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Environmental Conditions and Test Procedures for Airborne Equipment

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Prepared by SC-135
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Foreword

This document was prepared by Special Committee 135 (SC-135) and approved by the RTCA Program Management Committee (PMC) on December 8, 2010. It supersedes RTCA DO-160F dated December 6, 2007.

RTCA, Incorporated is a not-for-profit corporation formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public. The organization functions as a Federal Advisory Committee and develops consensus based recommendations on contemporary aviation issues. RTCA's objectives include but are not limited to:

- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;
- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;
- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunications Union and other appropriate international organizations can be based.

The organization's recommendations are often used as the basis for government and private sector decisions as well as the foundation for many Federal Aviation Administration technical Standard Orders.

Since RTCA is not an official agency of the United States Government, its recommendations may not be regarded as statements of official government policy unless so enunciated by the U.S. government organization or agency having statutory jurisdiction over any matters to which the recommendations relate.

These standards were coordinated by RTCA SC-135 with the European Organisation for Civil Aviation Equipment (EUROCAE). EUROCAE concurs with RTCA on the environmental conditions and test procedures set forth herein. When approved by EUROCAE, this document will be identified jointly as RTCA DO-160G/EUROCAE ED-14G.

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RTCA/DO-160G

**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 1

Purpose and Applicability

Section 2

Definitions of Terms

Section 3

Conditions of Tests

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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1 Purpose and Applicability

This document defines a series of minimum standard environmental test conditions (categories) and applicable test procedures for airborne equipment. The purpose of these tests is to provide a laboratory means of determining the performance characteristics of airborne equipment in environmental conditions representative of those which may be encountered in airborne operation of the equipment.

The standard environmental test conditions and test procedures contained herein may be used in conjunction with applicable equipment performance standards as a minimum specification under environmental conditions, which can ensure a sufficient degree of confidence in performance during operations.

Note: In each of the test procedures contained herein, the following phrase will be seen several times:

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The “applicable equipment performance standards” referred to are either:

- a. EUROCAE Minimum Operational Performance Specifications (formerly Requirements) (MOPS/MOPR).
- b. RTCA Minimum Performance Standards (MPS) and/or RTCA Minimum Operational Performance Standards (MOPS).
- c. The manufacturers equipment specification(s), where applicable.

Some of the environmental conditions and test procedures contained in this document are not necessarily applicable to all airborne equipment. The selection of the appropriate and/or additional environmental conditions and test procedures is the responsibility of the writers (authors) of the performance standards for the specific airborne equipment.

Notes:

1. There are several additional environmental conditions (categories), that specific airborne equipment may need to be evaluated against, that have not been included in this document. These include, but are not limited to: hail, acceleration and acoustic vibration.
2. The procedures for testing airborne equipment for special environmental conditions that are usually uniquely related to that specific type of airborne equipment, should be the responsibility of the writer (author) of the performance standard for that specific equipment.

3. The International System of Units (SI) is usually used throughout this document as the primary values. In certain instances, however, when the primary values were derived in US units, these units are used as the primary values.
4. Subject to the provisions of Subsection 3.2, it is permissible to use more than one test article.

The words airborne equipment, as used within this document, have direct applicability to most airborne equipment. It is the responsibility of those who wish to apply the test conditions and procedures contained in this document to determine the applicability of these test conditions and procedures to a specific equipment intended for installation on, or within, a specific or general class or type of aircraft.

Minimum operational performance standards (MOPS) prepared by RTCA, Inc. for airborne equipment contain requirements that the equipment must meet to ensure reliable operation in actual aeronautical installations. These equipment requirements must be verified in ambient and stressed environmental conditions. The MOPS typically contain recommended bench test procedures for ambient conditions, and refer to RTCA Document DO-160, "Environmental Conditions and Test Procedures for Airborne Equipment," for the stressed environmental testing. The test categories defined in DO-160 are intended to encompass the full spectrum of environmental conditions that airborne equipment may experience – from benign to very hostile.

The environmental conditions and test procedures defined herein are intended to determine only the performance of the airborne equipment under these environmental conditions and are not intended to be used as a measure of service life of the airborne equipment subjected to these tests.

Any regulatory application of this document is the sole responsibility of appropriate governmental (regulatory) agencies.

1.1 Historical Note, and General Guidance to Users

DO-160 (or its precursor, DO-138) has been used as a standard for environmental qualification testing since 1958. It has been referenced in Minimum Operational Performance Specifications (MOPS) for specific equipment designs, and is referenced in FAA Advisory Circulars as a means of environmental qualification for TSO authorization. It has been subject to a continuous process of upgrade and revision as new needs arose within the aviation community, as improved test techniques have emerged, and as the realities of equipment operation of under actual environmental conditions has become better understood.

Environmental stresses can result from natural forces or man made effects, and may be mitigated by details of the equipment installation. The categories that have been

developed over time reflect a reasonably mature understanding as to the severity of the stresses, the degrees of mitigation achievable in the design of an installation, and the robustness that must be designed into equipment in order to perform under the resultant stress. In order to fully reap the advantages of the maturity of this document, it is incumbent upon the designers of the installed equipment, as well as the designers of the host installation, to consider the categories defined herein as early in their programs as feasible. The categories defined within each environmental test procedure have proved to be a practical set of boundary conditions between the requirements of real world installations and the performance of installed equipment. Effective dialogue between the airframe and equipment designers is essential to ensure that correct categories are utilized.

1.2 DO-160 User Guides

Various sections within this document now contain User Guide material. This material appears at the end of the respective section. The User Guides provide background information for the associated test procedures and requirements in the main body of DO-160. This information includes rationale for requirements, guidance in applying the requirements, commentary, possible trouble shooting techniques and lessons learned from previous laboratory experience. This information is intended to help users understand the intent behind the requirements, and to help users develop detailed test procedures based on the general test procedures in this document. These User Guides are provided for guidance purposes. The User Guides do not contain requirements. Only the procedures in the body of each section are required to be applied to the EUT.

The User Guides follow the same general format as the main body of the section. Main body paragraph numbers are repeated in the User Guide.

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2 Definitions of Terms, General

This section contains the definitions of general terms that are utilized throughout this document. The definition of terms specific to a particular section may be found in the appropriate section.

2.1 Equipment Temperature Stabilization

a. Not Operating

The equipment is considered temperature stabilized when the temperature of the functioning parts of the test item considered to have the longest thermal lag are within three degrees Celsius of the specified test temperature. When temperature measurement of the largest internal mass is not practical, the minimum time considered applicable for temperature stabilization shall be three hours.

b. Operating

The equipment is considered temperature stabilized when the functioning parts of the test item considered to have the longest thermal lag do not vary by more than two degrees Celsius per hour. When temperature measurement of the largest internal mass is not practical, the minimum time considered applicable for temperature stabilization shall be two hours.

2.2 Maximum Duty Cycle

When operation of an equipment is periodic, the maximum duty cycle is the relationship between the maximum length of time for which the equipment is designed to operate at its rated capacity and the length of time during which the equipment is not operating; or when the operating capacity is at a defined minimum. The maximum duty cycle shall be established by the equipment specification.

2.3 Not Operating

Not operating is that condition wherein no power is applied to the equipment unless otherwise defined in the individual equipment specification.

2.4 Controlled or Partially Controlled Temperature Locations

A controlled or partially controlled temperature location is a space within an aircraft in which the temperature of the air is maintained by an environmental control system (see Table 4-1 of applicable category).

2.5 Total Excursion

Total excursion means the total displacement from positive maximum to negative maximum.

2.6 Equipment

The term “equipment” includes the test items and all of the components or units necessary (as determined by the equipment manufacturer) for the equipment to properly perform its intended function(s). The equipment shall be representative of the production standard that will be utilized in service.

2.7 Altitude

Altitude represents the environmental pressure relative to sea level to which the equipment is exposed during the tests.

2.8 Category of Tests and Declarations

For each environmental condition addressed in this document, the equipment supplier should select, from categories defined within the particular sections, a category which best represents the most severe environment which the equipment is expected to be regularly exposed to during its service life. An exception to this rule is the use of Category X as explained below. The selected categories selections are to be tabulated on the Environmental Qualification Form in accordance with the guidelines presented in Appendix A.

For any category listed on the Environmental Qualification form it can be derived that the equipment would also be able to perform its intended function(s) when exposed to categories that can be assessed as being less severe.

Use of Category X on the environmental qualification form in association with any environmental test procedure of this document is reserved for the case where the equipment supplier wishes to indicate that compliance with equipment performance standards has not been demonstrated under the environmental conditions addressed by that particular procedure.

If any category listed on the Environmental Qualification Form is not sufficient for a specific aircraft certification, then additional testing may be required.

When the statement “DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS” is found at the end of or during the test procedures, it should be understood that performance compliance and verification is considered to be the requirement that allows the equipment to be certified as to its ability to perform its intended function(s) during and/or after a specific test category.

2.9 Applicability of Test Results

The results of the testing using these procedures are only valid for the test configuration (test set up, external configuration and internal configuration) used during the qualification tests. Any change from this configuration, either externally or internally (such as: PCB lay-out, component change inside the unit, installation wiring, etc.) must be assessed to ensure that the test results are still applicable. If an assessment cannot show that the results are still applicable, re-testing is required.

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3 Conditions of Tests

3.1 Connection and Orientation of Equipment

Unless otherwise stated, connect and orient the equipment (e.g. mechanically and electrically) as recommended by the equipment manufacturer for normal service installation, including any cooling provisions, as necessary to perform the tests and to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Interconnecting cable lengths, where not specified, shall be at least 1.50 m long and shall be configured so as to allow one common bundle of 1.20 m. Any inputs or outputs to or from other equipment(s) normally associated with the equipment(s) under test shall be connected or adequately simulated.

Note: Paragraphs 19.3 and 20.3, if applicable, will require an interconnecting cable longer than these minimums.

3.2 Order of Tests, Multiple Test Articles

It is the responsibility of the equipment manufacturer to determine any requirements for cumulative or combined testing, and to reflect these requirements in the equipment specification and test plan. Insofar as any such requirements are not compromised, multiple test articles may be used, tests may be performed in any order, and separate test articles may be used for demonstrating compliance with the separate tests.

Note: In cases where cumulative testing is required, or multiple tests are to be performed upon a single test article, the following provisions shall apply:

- a. The salt fog test shall not be conducted prior to the fungus resistance test.
- b. The sand and dust test shall not be conducted prior to the fungus resistance, salt fog, or humidity tests.
- c. The explosive atmosphere tests shall not be conducted prior to any other DO-160 tests.
- d. The flammability tests shall not be conducted prior to any other DO-160 tests.

3.3 Combining Tests

It is acceptable to employ alternate procedures developed as combinations of the procedures described herein, provided it can be demonstrated that all applicable environmental conditions specified in the original procedures are duplicated or exceeded in the combined procedure. If alternate procedures are used, appropriate information should be provided along with the Environmental Qualification Form, (see Appendix A).

3.4 Measurement of Air Temperature in the Test Chamber

The temperature of the air in the test chamber shall be measured at a location where the air conditions are representative of that immediately surrounding the equipment. Measurement of chamber wall temperature is not suitable, due to temperature lag and heat transfer through the chamber wall.

A means of circulating air in the test chamber should be employed to assure an approximate uniform air temperature condition throughout the chamber. When such means are employed, the air movement shall not be directed on the equipment under test, and the equipment shall be tested at the minimum flow rate consistent with the purpose of maintaining a uniform temperature distribution in the chamber. The ambient air velocities surrounding equipment not requiring auxiliary cooling shall remain comparable to those air velocities that occur from natural convection.

For equipment that requires auxiliary cooling to assure proper operation, as defined in the equipment installation instructions, the following applies:

- a. If air is the cooling medium, the supplied cooling air characteristics shall be the same as the specified chamber air characteristics, unless otherwise specified by the equipment manufacturer.
- b. If the cooling medium is not air, the medium and its supply temperature shall be as specified by the equipment manufacturer.

Note: For equipment whose installation location is known and defined relative to other equipment, sources of radiated heat and/or impediments to normal convection should be simulated in the test.

3.5 Ambient Conditions

Unless otherwise specified, all tests shall be made within the following ambient conditions:

- a. Temperature: +15 to +35 degrees Celsius.
- b. Relative Humidity: Not greater than 85 percent.
- c. Ambient Pressure: 84 to 107 kPa (equivalent to +5,000 to -1,500 ft) (+1525 to -460 m).

When tests are conducted at ambient conditions that differ from the above values, the actual conditions shall be recorded.

3.6 Environmental Test Condition Tolerances

Unless otherwise specified, tests made at environmental conditions other than ambient, as defined above, shall be conducted subject to the following tolerances:

- a. Temperature: $\langle \equiv \sim 3$ degrees Celsius.
- b. Altitude: $\langle \equiv \sim 5$ percent of specified pressure.

3.7 Test Equipment

All stimulus and measurement equipment used in the performance of the tests should be identified by make, model, serial number and the calibration expiration date and/or the valid period of calibration where appropriate. When appropriate, all test equipment calibration standards should be traceable to national and/or international standards.

3.8 Multiple Unit Equipment

If the equipment to be tested consists of several separate units, these units may be tested separately, provided the functional aspects are maintained as defined in the relevant equipment specification.

3.9 EUT Configuration for Susceptibility Tests

During any environmental test of electrical and electronic equipment (for example, susceptibility test) conducted per this document, the equipment under test shall be configured in the most sensitive functioning mode that could be encountered during its normal operation in the field. When the equipment is embedded with basic and/or application software, it must be tested with software functions, operating (or simulated), to exhibit the maximum sensitivity to the test environment. The description and the justification for the functional configuration, including software, shall be reported or referenced in the test report.

Unless otherwise specified in the applicable minimum performance standard, special purpose test firmware/software is acceptable provided that the hardware and interfaces are comprehensively exercised and yields good test coverage based on validated requirements, and the configuration is controlled. The special purpose test firmware/software, when used, should be capable of thoroughly exercising the hardware functions.

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 4

Temperature and Altitude

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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4.0 Temperature and Altitude

4.1 Purpose of the Tests

These tests determine the performance characteristics of equipment at the applicable categories for the temperatures and altitudes specified in Table 4-1 and at the pressures defined in Table 4-2.

4.2 General

Several temperature and altitude test procedures are defined, each to be selected according to the category for which the equipment is designed to be used when installed in an aircraft (see Subsection 4.3 and Table 4-1).

Note: The selection of a temperature/altitude category depends on the location in (or on) the aircraft, the maximum operating altitude of the aircraft and whether the equipment is located within a temperature and/or pressure controlled area. The above conditions must be taken into consideration by the equipment designer in evaluating these requirements, which are determined by the end application and use of the equipment.

4.3 Equipment Categories

The following categories cover the wide range of environments known to exist in the majority of aircraft types and installation locations. It should be recognized that not all possible combinations of temperatures and altitude limits are covered in these equipment categories. Categories for in-flight loss of cooling are defined in paragraph 4.5.5.

Category A1

Equipment intended for installation in a controlled temperature and pressurized location, on an aircraft within which pressures are normally no lower than the altitude equivalent of 15,000 ft (4,600 m) Mean Sea Level (MSL), is identified as Category A1. This category may also be applicable to equipment installed in temperature controlled but unpressurized locations on an aircraft that operates at altitudes no higher than 15,000 ft (4,600 m) MSL.

Category A2

Equipment intended for installation in a partially controlled temperature but pressurized location on an aircraft within which the pressures are normally no lower than the altitude equivalent of 15,000 ft (4,600 m) MSL is identified as Category A2. This category may also be applicable to equipment installed in partially controlled temperature but unpressurized locations on an aircraft that operates at altitudes no higher than 15,000 ft (4,600 m) MSL.

Category A3

Equipment intended for installation in a controlled or partially controlled temperature but pressurized location within an aircraft within which the pressures are normally no lower than the altitude equivalent of 15,000 ft (4,600 m) MSL, where the temperatures will be more severe than those for categories A1 and A2, is identified as Category A3.

Category A4

Equipment intended for installation in a controlled temperature and pressurized location, on an aircraft within which pressures are normally no lower than the altitude equivalent of 15,000 ft. (4,600m) Mean Sea Level (MSL), for which temperature requirements differ from category A1 as declared by the equipment manufacturer. This category may also be applicable to equipment installed in a temperature controlled but unpressurized locations on an aircraft that operates at altitudes no higher than 15,000ft. (4,600m) MSL, for which temperature requirements differ from category A1 as declared by the equipment manufacturer.

Category B1

Equipment intended for installation in a non-pressurized but controlled temperature location in an aircraft that is operated at altitudes up to 25,000 ft (7,620 m) MSL is identified as Category B1.

Category B2

Equipment intended for installation in non-pressurized and non-controlled temperature locations on an aircraft that is operated at altitudes up to 25,000 ft (7,620 m) MSL is identified as Category B2.

Category B3

Equipment intended for installation in the power plant compartment of an aircraft that is operated at altitudes up to 25,000 ft (7,620 m) MSL is identified as Category B3.

Category B4

Equipment intended for installation in a non-pressurized location on an aircraft that is operated at altitudes up to 25,000 ft (7,620 m) MSL, for which temperature requirements differ from B1 and B2, is identified as Category B4.

Category C1

Equipment intended for installation in a non-pressurized but controlled temperature location in an aircraft that is operated at altitudes up to 35,000 ft (10,700 m) MSL is identified as Category C1.

Category C2

Equipment intended for installation in non-pressurized and non-controlled temperature locations within an aircraft that is operated at altitudes up to 35,000 ft (10,700 m) MSL is identified as Category C2.

Category C3

Equipment intended for installation in the power plant compartment of an aircraft that is operated at altitudes up to 35,000 ft (10,700 m) MSL is identified as Category C3.

Category C4

Equipment intended for installation on a non-pressurized aircraft that is operated at altitudes up to 35,000 ft (10,700 m) MSL, for which temperature requirements differ from C1 and C2, is identified as Category C4.

Category D1

Equipment intended for installation in a non-pressurized but controlled temperature location on an aircraft that is operated at altitudes up to 50,000 ft (15,200 m) MSL is identified as Category D1.

Category D2

Equipment intended for installation in non-pressurized and non-controlled temperature locations on an aircraft that is operated at altitudes up to 50,000 ft (15,200 m) MSL is identified as Category D2.

Category D3

Equipment intended for installation in the power plant compartment of an aircraft that is operated at altitudes up to 50,000 ft (15,200 m) MSL is identified as Category D3.

Category E1

Equipment intended for installation in non-pressurized and non-controlled temperature locations on an aircraft that is operated at altitudes up to 70,000 ft (21,300 m) MSL is identified as Category E1.

Category E2

Equipment intended for installation in the power plant compartment of an aircraft that is operated at altitudes up to 70,000 ft (21,300 m) MSL is identified as Category E2.

Category F1

Equipment intended for installation in non-pressurized but controlled temperature locations on an aircraft that is operated at altitudes up to 55,000 ft (16,800 m) MSL is identified as Category F1.

Category F2

Equipment intended for installation in non-pressurized and non-controlled temperature locations on an aircraft that is operated at altitudes up to 55,000 ft (16,800 m) MSL is identified as Category F2.

Category F3

Equipment intended for installation in the power plant compartment of an aircraft that is operated at altitudes up to 55,000 ft (16,800 m) MSL is identified as Category F3.

4.4 Definitions of Terms

Operating Low Temperature

Operating low temperature is the lowest temperature at which equipment will normally be exposed and be required to operate.

Operating High Temperature

The operating high temperature values given in Table 4-1 are the maximum levels that the equipment will be exposed to within the particular installation area, e.g. in an enclosed space behind an instrument panel, equipment racks, power plant areas, etc., under normal operating conditions.

Short-Time Operating Temperature

These are startup conditions where equipment is turned on following a ground soak. It is expected that these temperature conditions will occur infrequently and be of short duration, since cooling or heating air circulation or other means of controlling temperature would be enabled concurrent with equipment operation.

Ground Survival Temperatures

These are the lowest and highest ground temperatures that the equipment is normally expected to be exposed to during aircraft storage or exposure to climatic extremes. The equipment is not expected to operate within specification limits at these temperatures but is expected to survive without damage.

In-Flight Loss of Cooling

This condition represents the failure of the external or internal system that normally provides dedicated cooling for the equipment. Certain equipment must survive for a limited time in the absence of cooling. Test requirements for this type of equipment shall be specified in the equipment performance specification.

4.5 Temperature Tests

4.5.1 Ground Survival Low Temperature Test and Short-Time Operating Low Temperature Test

At the ambient pressure and with the equipment not operating, stabilize the equipment at the appropriate ground survival low temperature specified in Table 4-1. Maintain this temperature for at least three hours. Then with the equipment not operating, increase the temperature to the

short time operating low temperature specified in Table 4-1 at a minimum rate of 2°C/minute. Once the temperature has reached the short-time operating low temperature, soak the equipment for 30 +5/-0 minutes or until internal stabilization is established. Place the equipment into the operating state and maintain the test chamber air temperature at the appropriate short time operating low temperature specified in Table 4-1. Operate the equipment for at least 30 minutes. Verify equipment operation per note 1 during this operating period. The test profile is shown graphically in Figure 4-1.

- Note:*
- 1) *This test simulates temperature conditions that may be encountered by equipment while the aircraft is on the ground. In determining the level of performance required during the period of this test, the operational requirements of the particular equipment or systems shall be stated in the test procedure and report or in the specific equipment performance standard.*
 - 2) *If the short time operating low temperature and operating low temperature are the same, the short-time operating low temperature need not be conducted. The ground survival low temperature test may not be deleted, even if the short-time operating low temperature is identical to the operating low temperature. Power should be applied at the operating low temperature after the un-powered low temperature soak specified in paragraph 4.5.1.*

4.5.2 Operating Low Temperature Test

With the equipment operating, adjust the test chamber air temperature to the appropriate operating low temperature specified in Table 4-1 at ambient pressure. After the equipment temperature has become stabilized, operate the equipment for a minimum of two hours while maintaining the temperature of the air in the test chamber at the operating low temperature. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during this operating period. The test profile is shown graphically in figure 4-2.

4.5.3 Ground Survival High Temperature Test and Short-Time Operating High Temperature Test

At ambient pressure and with the equipment not operating, stabilize the equipment at the appropriate ground survival high temperature of Table 4-1. Maintain this temperature for at least three hours. Then with the equipment not operating, reduce the temperature to the short-time operating high temperature specified in Table 4-1 at a minimum rate of 2°C/minute. Once the temperature has reached the short-time operating high temperature, soak the equipment for 30 +5/-0 minutes or until internal stabilization is established. Place the equipment into the operating state and maintain the test chamber air temperature at the appropriate short-time operating high temperature specified in Table 4-1. Operate the equipment for at least 30 minutes. Verify equipment operation per note 1 during this operating period. The test profile is shown graphically in Figure 4-3.

- Note:*
- 1) *This test simulates temperature conditions that may be encountered by equipment while the aircraft is on the ground. In determining the level of performance required during the period of this test, the operational requirements of the particular equipment or systems shall be stated in the test procedure and report or in the specific equipment performance standard.*

2) *If the short-time operating high temperature and operating high temperature are the same, the short-time operating high temperature test need not be conducted. The ground survival high temperature test may not be deleted, even if the short-time high temperature is identical to the operating high temperature. Power should be applied at the operating high temperature after the un-powered high temperature soak specified in paragraph 4.5.3.*

4.5.4 Operating High Temperature Test

With the equipment operating, adjust the test chamber air temperature to the appropriate operating high temperature specified in Table 4-1 at ambient pressure. After the equipment temperature has become stabilized, operate the equipment for a minimum of two hours while maintaining the temperature of the air in the test chamber at the operating high temperature. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the operating period. The test profile is shown graphically in Figure 4-4.

4.5.5 In-Flight Loss of Cooling Test

Categories of In-Flight Loss of Cooling Test Periods are defined by periods during which cooling is removed.

Category V - 30 minutes minimum
Category W - 90 minutes minimum
Category P - 180 minutes minimum
Category Y - 300 minutes minimum
Category Z - As defined in the equipment specification

With the equipment operating at ambient room pressure, and with cooling air supplied in accordance with the conditions specified in Subsection 3.4, adjust the test chamber air temperature to the value specified in Table 4-1 for the loss of cooling test, and allow the equipment temperature to stabilize. Turn off the equipment cooling air supply, and operate the equipment for the period of time specified for the applicable category while maintaining the temperature of the air in the test chamber at the value specified in Table 4-1. During this period DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. The test profile is shown graphically in Figure 4-5.

Note: This test applies to equipment that requires cooling for proper operation during the operating high temperature test, paragraph 4.5.4, has functions whose failure following in-flight loss of cooling would contribute to or cause a failure condition that would prevent the continued safe flight and landing of the airplane, and in which the cooling is externally supplied or powered.

4.6 Altitude, Decompression and Overpressure Tests

Refer to Table 4-1 for altitude and to Table 4-2 for pressure values.

4.6.1 Altitude Test

Conduct this test at ambient temperature. Operate the equipment at maximum duty cycle. Decrease the pressure in the test chamber to the appropriate maximum operating altitude specified in [Table 4-1](#). Allow the equipment temperature to stabilize. Maintain this pressure for at least two hours. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the two-hour period or at the maximum duty cycle, whichever is longer. The test profile is shown graphically in [Figure 4-6](#).

Note: When the equipment manufacturer requires that the equipment be tested for spark-producing conditions at altitude, Sections 9.6a and 9.6b may apply. If so, the procedures of 9.7 shall be conducted at the maximum test altitude, and paragraph 3.3 (Combining Tests) may be applicable.

4.6.2 Decompression Test

Conduct this test at ambient temperature. With the equipment operating, adjust the absolute pressure to an equivalent altitude of 8,000 ft (2,400 m) MSL and allow the equipment temperature to stabilize. Reduce the absolute pressure to the equivalent of the maximum operational altitude for the aircraft on which the equipment will be installed (see [Table 4-1](#)). This reduction in pressure shall take place within 15 seconds. Maintain this reduced pressure for at least 10 minutes or as specified in the equipment specification. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the period at maximum operating altitude. The test profile is shown graphically in [Figure 4-7](#).

Note: The decompression test is intended for equipment as follows:

- 1) Equipment installed in pressurized areas on the aircraft required to operate during and following an emergency descent.*
- 2) Equipment utilizing high voltage electrical/electronics circuits, i.e. displays etc...*

Equipment intended for installation in areas that are subject to partial pressurization shall be tested in accordance with paragraph 4.6.1 above.

4.6.3 Overpressure Test

With the equipment not operating, unless otherwise specified in the equipment specification, subject the equipment to an absolute pressure equivalent to -15,000 ft altitude (170 kPa). Maintain this condition for at least 10 minutes. Return the equipment to the ambient atmospheric pressure and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. The test profile is shown graphically in [Figure 4-8](#).

Note: 1) This test is for equipment installed in pressurized areas. The test determines whether the equipment will withstand cabin overpressures resulting from routine aircraft pressurization system testing.

2) Equipment installed in a pressurized area and whose internal sections are vented external to the pressurized area shall have these internal sections exposed to the pressure specified in the equipment specification during the overpressure test.

Table 4-1 Temperature and Altitude Criteria

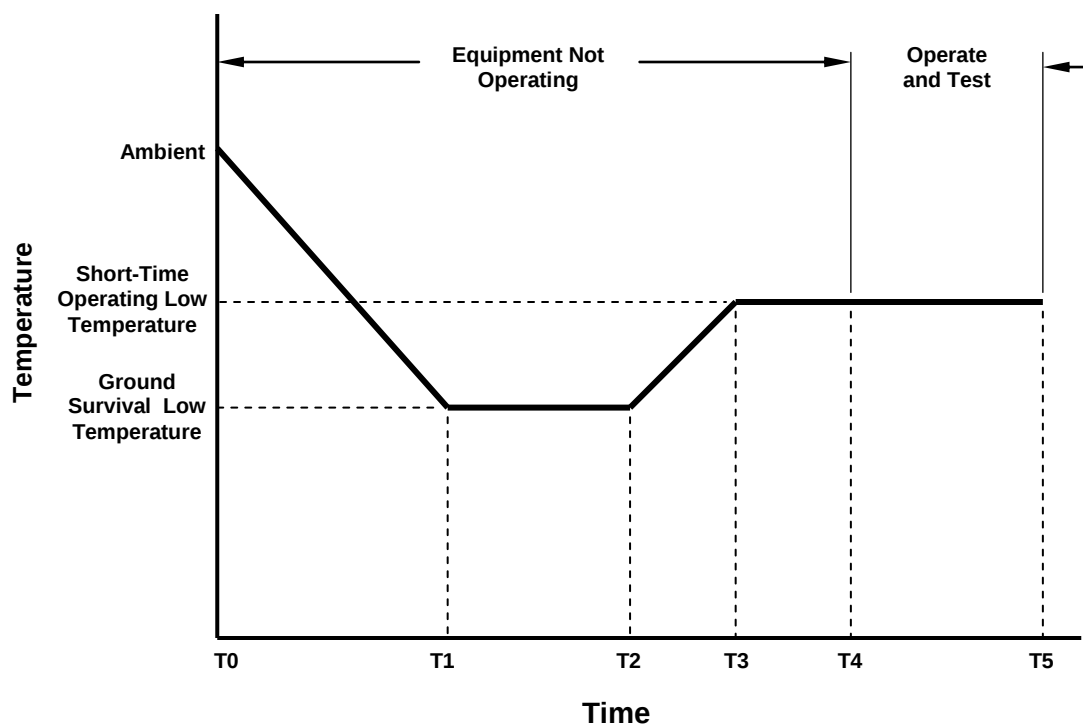
Environmental Tests	Category Paragraph 4.3																			
	A				B				C				D			E		F		
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	1	2	1	2	3
Operating Low Temp.	-15	-15	-15	-15	-20	-45	-45	Note (4)	-20	-55	-55	Note (4)	-20	-55	-55	-55	-55	-20	-55	-55
Degrees C Paragraph 4.5.2																				
Operating High Temp.	+55	+70	+70	Note (3)	+55	+70	Note (3)	Note (4)	+55	+70	Note (3)	Note (4)	+55	+70	Note (3)	Note (3)	Note (3)	+55	+70	Note (3)
Degrees C Paragraph 4.5.4																				
Short-Time Operating Low Temp.	-40	-40	-40	Note (3)	-40	-45	Note (3)	Note (4)	-40	-55	Note (3)	Note (4)	-40	-55	-55	-55	-55	-40	-55	-55
Degrees C Paragraph 4.5.1																				
Short-Time Operating High Temp.	+70	+70	+85	Note (3)	+70	+70	Note (3)	Note (4)	+70	+70	Note (3)	Note (4)	+70	+70	Note (3)	Note (3)	Note (3)	+70	+70	Note (3)
Degrees C Paragraph 4.5.3																				
Loss of Cooling Test	+30	+40	+45	Note (3)	+30	+40	Note (3)	Note (3)	+30	+40	Note (3)	Note (3)	+30	+40	Note (3)	Note (3)	Note (3)	+30	+40	Note (3)
Degrees C Paragraph 4.5.5																				
Ground Survival Low Temperature	-55	-55	-55	Note (3)	-55	-55	Note (3)	-55	-55	-55	Note (3)	-55	-55	-55	-55	-55	-55	-55	-55	-55
Degrees C Paragraph 4.5.1																				
Ground Survival High Temperature	+85	+85	+85	Note (3)	+85	+85	Note (3)	+85	+85	+85	Note (3)	+85	+85	+85	Note (3)	+85	Note (3)	+85	+85	Note (3)
Degrees C Paragraph 4.5.3																				
Altitude	15	15	15	15	25	25	25	25	35	35	35	35	50	50	50	70	70	55	55	55
Thousands of Feet Thousands of Meters Paragraph 4.6.1	4.6	4.6	4.6	4.6	7.6	7.6	7.6	7.6	10.7	10.7	10.7	10.7	15.2	15.2	15.2	21.3	21.3	16.8	16.8	16.8
Decompression Test	Note (1)	Note (1)	Note (1)	Note (1)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Paragraph 4.6.2	(4)	(4)	(4)	(4)																
Overpressure Test	Note (2)	Note (2)	Note (2)	Note (2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Paragraph 4.6.3																				

Note:

- 1) The lowest pressure applicable for the decompression test is the maximum operating altitude for the aircraft in which the equipment will be installed.
- 2) The absolute pressure is 170 kPa (-15,000 ft or -4,600 m).
- 3) To be declared by the equipment manufacturer relative to temperature extremes.
- 4) To be declared by the equipment manufacturer and defined in the manufacturer's installation instructions when specific critical criteria exist.

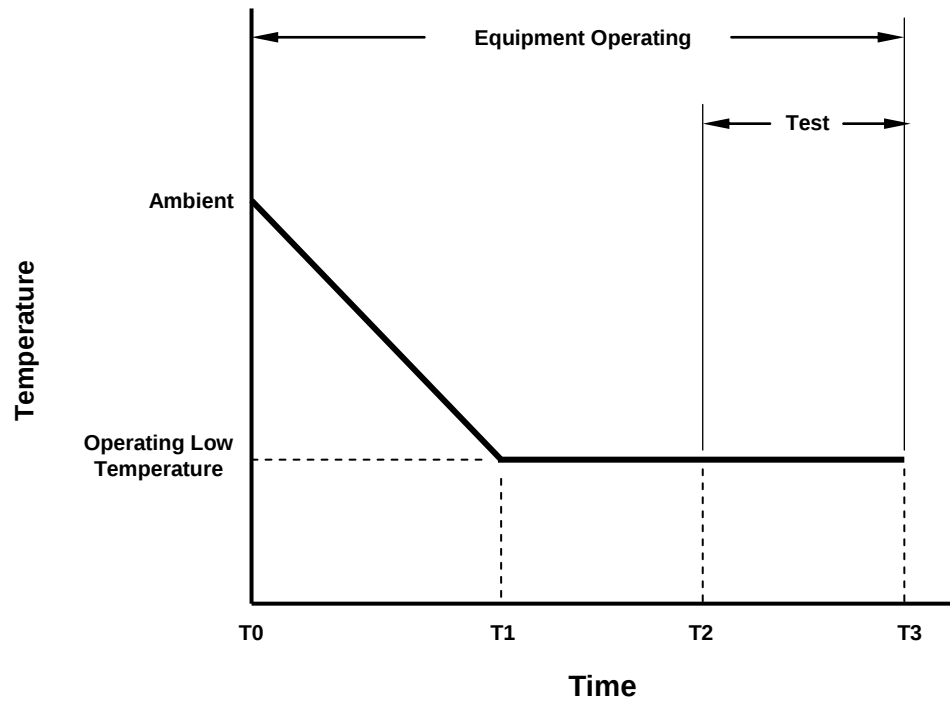
Table 4-2 Pressure Values for Various Pressure Altitude Levels

Pressure Altitude	Absolute Pressure			
	kPa	(mbars)	(in Hg)	mm Hg
-15,000 ft (-4,572 m)	169.73	1697.3	50.12	1273.0
-1,500 ft (-457 m)	106.94	1069.4	31.58	802.1
0 ft (0m)	101.32	1013.2	29.92	760.0
+8,000 ft (+2,438 m)	75.26	752.6	22.22	564.4
+15,000 ft (+4,572 m)	57.18	571.8	16.89	429.0
+25,000 ft (+7,620 m)	37.60	376.0	11.10	282.0
+35,000 ft (+10,668 m)	23.84	238.4	7.04	178.8
+50,000 ft (+15,240 m)	11.60	116.0	3.42	87.0
+55,000 ft (+16,764 m)	9.12	91.2	2.69	68.3
+70,000 ft (+21,336 m)	4.44	44.4	1.31	33.3



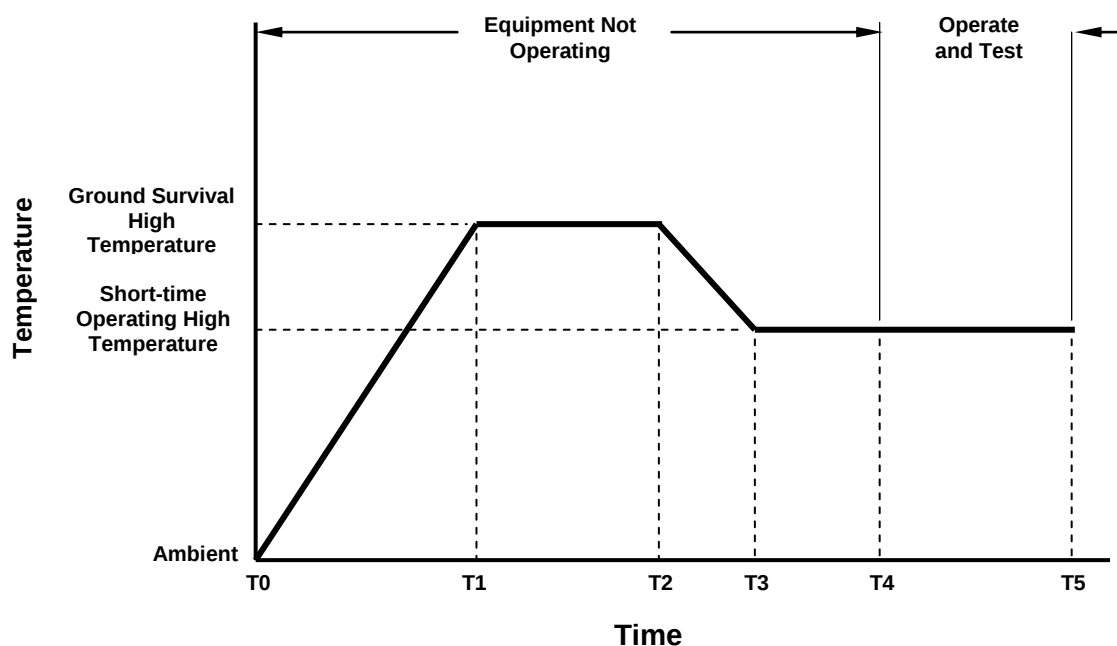
- Note:
- 1) Temperature change rate from T0 to T1 is not specified.
 - 2) T1 to T2 is time for equipment temperature stabilization time, plus a minimum of three hours.
 - 3) T2 to T3 is at a minimum rate of 2°C/minute
 - 4) T3 to T4 is 30 +5/-0 minutes or the time for internal stabilization.
 - 5) T4 to T5 is 0.5 hours, minimum.
 - 6) If the Short-Time Low and Ground Survival Low Temperatures are identical, the time from T2 to T4 is zero.
 - 7) See Note 2 of the test procedure if the short-time low operating temperature is the same as the operating low temperature.

Figure 4-1 **Ground Survival Low Temperature and Short-Time Operating Low Temperature Test**



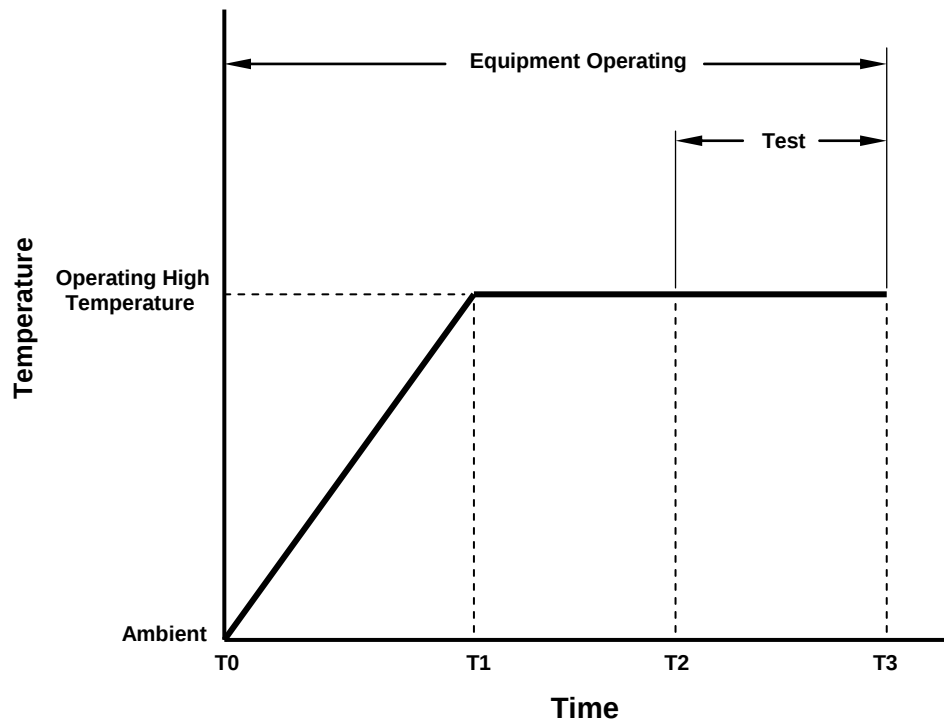
- Note:
- 1) Temperature change rate from T0 to T1 is not specified.
 - 2) T1 to T2 is time for equipment temperature to stabilize.
 - 3) T2 to T3 is 2.0 hours, minimum.

Figure 4-2 Operating Low Temperature Test



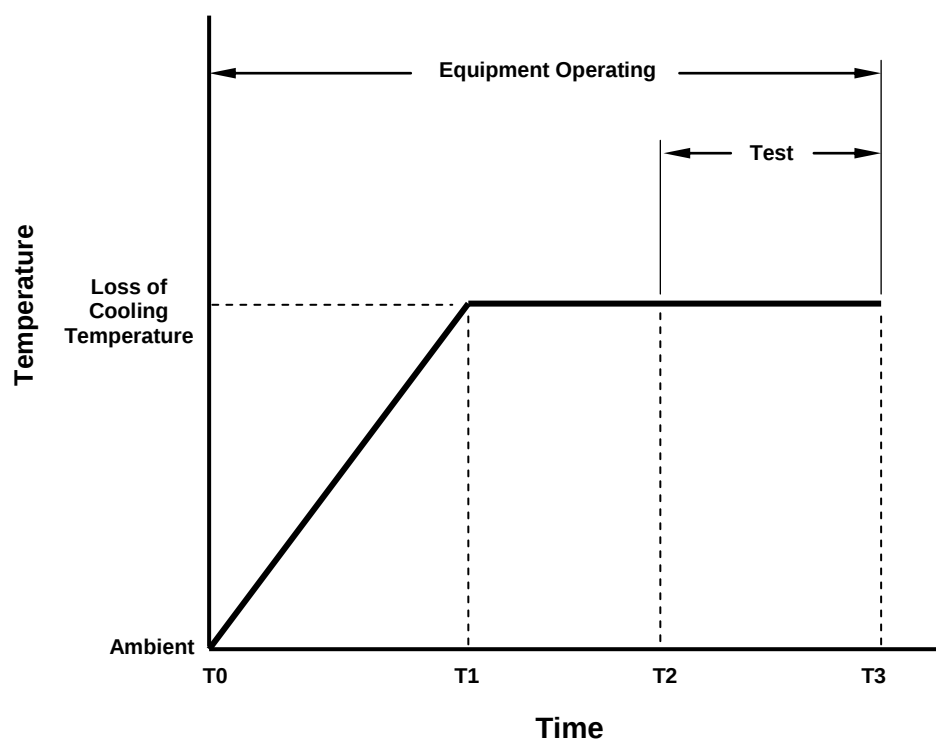
- Note:*
- 1) *Temperature change rate from T0 to T1 is not specified.*
 - 2) *T1 to T2 is time for equipment temperature stabilization time, plus a minimum of three hours.*
 - 3) *T2 to T3 is at a minimum rate of 2°C/minute*
 - 4) *T3 to T4 is 30 +5/-0 minutes or the time for internal stabilization.*
 - 5) *T4 to T5 is 0.5 hours, minimum.*
 - 6) *If the short-time high and ground survival high temperatures are identical, the time from T2 to T4 is zero.*
 - 7) *See Note 2 of the test procedure if the short-time high operating temperature is the same as the operating high temperature.*

Figure 4-3 Ground Survival High Temperature and Short-Time Operating High Temperature Test



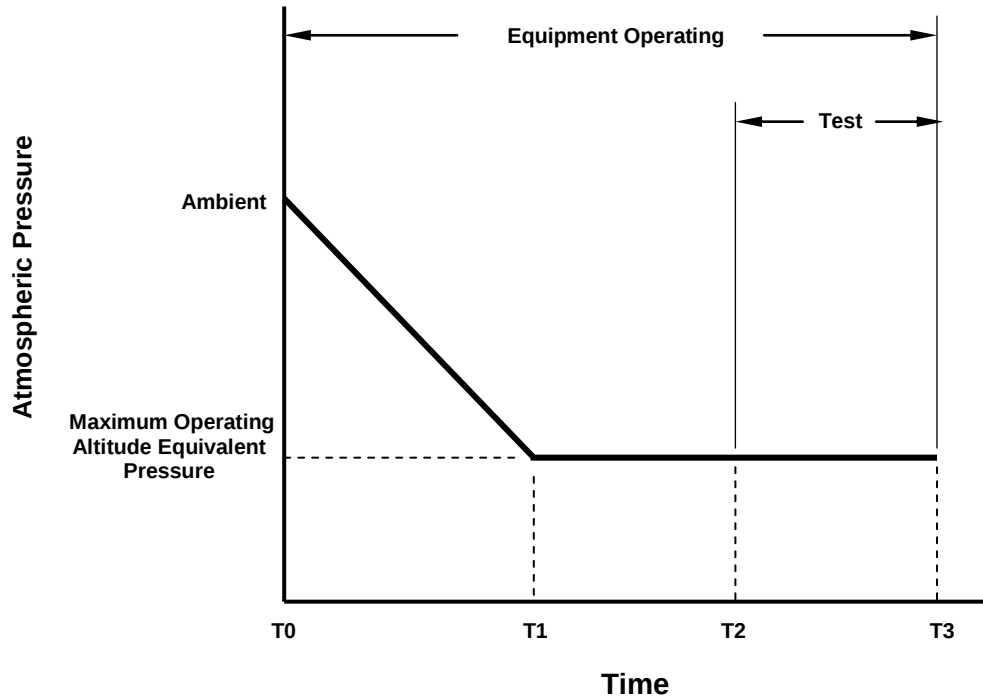
- Note:*
- 1) *Temperature change rate from T0 to T1 is not specified.*
 - 2) *T1 to T2 is time for equipment temperature to stabilize.*
 - 3) *T2 to T3 is 2.0 hours, minimum.*

Figure 4-4 Operating High Temperature Test



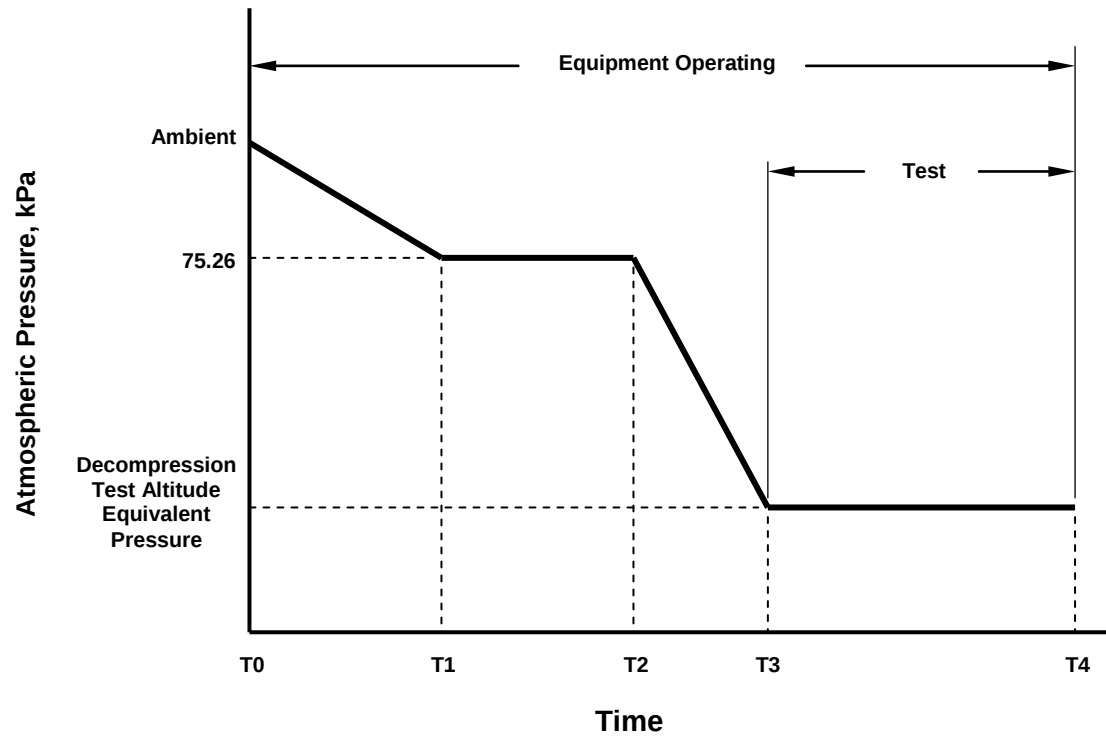
- Note:*
- 1) *Temperature change rate from T0 to T1 is not specified.*
 - 2) *T1 to T2 is time for equipment temperature to stabilize.*
 - 3) *See paragraph 4.5.4 for time duration T2 to T3.*

Figure 4-5 In-Flight Loss of Cooling Test



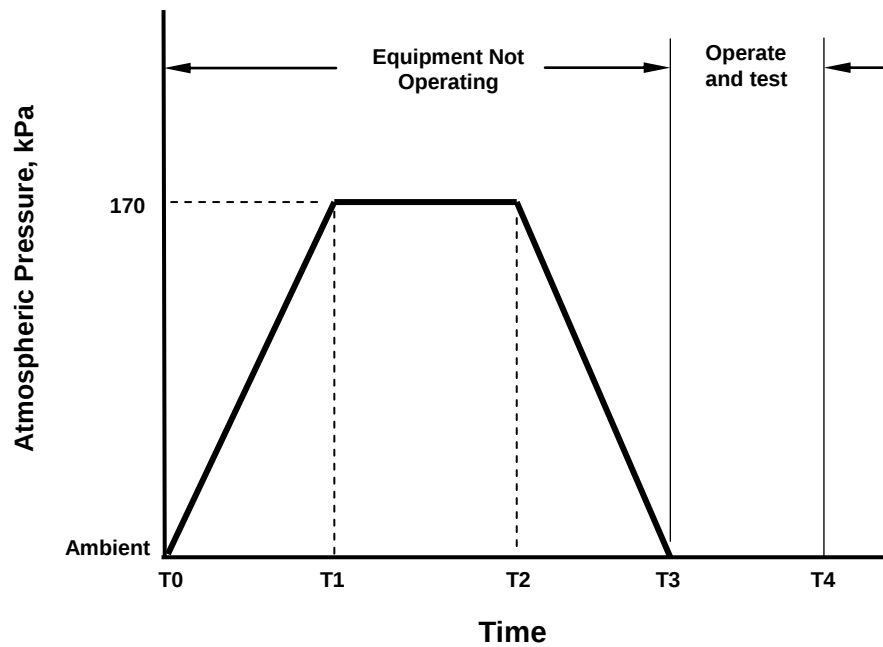
- Note:
- 1) Pressure change rate from T_0 to T_1 is not specified.
 - 2) T_1 to T_2 is time for equipment temperature to stabilize.
 - 3) T_2 to T_3 is 2.0 hours, minimum.

Figure 4-6 Altitude Test



- Note:
- 1) Pressure change rate from T0 to T1 is not specified
 - 2) T1 to T2 is time for equipment temperature to stabilize
 - 3) T2 to T3 is 15 seconds, maximum
 - 4) T3 to T4 is 10 minutes, minimum

Figure 4-7 Decompression Test



- Note:*
- 1) *Pressure change rates from T0 to T1 and from T2 to T3 are not specified.*
 - 2) *T1 to T2 is 10 minutes, minimum.*
 - 3) *T3 to T4 is minimum time necessary to operate and test equipment.*

Figure 4-8 Overpressure Test

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 5

Temperature Variation

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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5.0 Temperature Variation

5.1 Purpose of the Test

This test determines performance characteristics of the equipment during temperature variations between high and low operating temperature extremes. The applicable categories for flight operations are shown in Table 4-1. For categories A, B, and C, it is required that the equipment be subjected to the temperature variation test in 5.3.1 when such equipment is tested according to the procedures contained in Paragraphs 4.5.1, 4.5.2, 4.5.3, and 4.5.4. For categories S1 and S2, it is required that the equipment be subjected to the temperature shock test per Paragraph 5.3.2 or 5.3.3.

Note: The test is not intended to verify the behavior of the equipment in wet or icing conditions. In conducting this test, the test chamber may incorporate the capability of controlling or altering humidity to the extent that condensation is minimized or does not occur.

5.2 Temperature Change Rates

The rates applicable to the temperature variation procedures defined in Subsection 5.3 are as follows:

Category A - For equipment external to the aircraft or internal to the aircraft:

10 degrees Celsius minimum per minute.

Category B - For equipment in a non-temperature-controlled or partially temperature controlled internal section of the aircraft:

5 degrees Celsius minimum per minute.

Category C - For equipment in a temperature-controlled internal section of the aircraft:

2 degrees Celsius minimum per minute.

Category S1 - For equipment external to the aircraft or internal to the aircraft:

Known rate of change greater than 10 degrees Celsius per minute. The rate of change shall be noted in the Qualification Form.

Category S2 - For equipment external to the aircraft or internal to the aircraft:

Unknown rate of change greater than 10 degrees Celsius per minute.

Note: 1) *Equipment qualified to Category B is considered to have met Category C.*

2) *Rates of change greater than 10 degrees Celsius minimum per minute are considered as temperature shocks. Categories S1 and S2 are intended to evaluate the effects of more rapid or sudden temperature changes to the*

equipment. The outer surfaces, regions, or interfaces of the equipment may be of primary interest during temperature shock as the internal regions can have comparatively long time constants to reach stabilization.

- 3) *For Categories S1 and S2, Thermal Shock, Category S2 shall be used unless the temperature change rate is known, then Category S1 may be used.*

5.3 Test Procedures

5.3.1 Test Procedure Categories A, B, and C

The temperature variation test (except for Categories S1 and S2) can be combined to include the procedures of the ground survival low temperature test and short-time operating low temperature test, Paragraph 4.5.1, the operating low temperature test, Paragraph 4.5.2, the ground survival high temperature test short-time operating high temperature test, Paragraph 4.5.3, and the operating high temperature test, Paragraph 4.5.4. The following procedures shall apply:

- a. If the test is a combined test, proceed in accordance with Paragraph 4.5.1, which describes the ground survival low temperature test and the short-time operating low temperature test, and Paragraph 4.5.2, the operating low temperature test without transition to ambient temperature. After completion of the test defined in Paragraph 4.5.1 and 4.5.2, proceed to Subparagraph c. If the test is not a combined test, commencing at ambient temperature with the equipment operating, lower the temperature in the chamber towards the operating low temperature level at the applicable rates specified in Subsection 5.2.
- b. Stabilize the equipment in the operating mode at this operating low temperature level.
- c. Raise the temperature in the chamber towards the operating high temperature at the applicable rate specified in Subsection 5.2. During this temperature change, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.
- d. Stabilize the equipment at the operating high temperature. If this is a combined test, proceed in accordance with Paragraph 4.5.3, the ground survival high temperature test and short-time operating high temperature test, and subsequently Paragraph 4.5.4, the operating high temperature test without transition to ambient temperature. Maintain the equipment in a non-operating state for a minimum of 2 minutes.
- e. Turn the equipment on and lower the temperature in the chamber towards the operating low temperature level at the applicable rate specified in Subsection 5.2. During this temperature change DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.
- f. Stabilize the equipment temperature with the chamber at the operating low temperature, and then operate the equipment for at least one hour. Then turn off the equipment for 30 minutes, and restart the equipment while maintaining the chamber at the operating low temperature.
- g. Change the temperature of the chamber towards the ambient temperature at the applicable rate specified in Subsection 5.2.

-
- h. Stabilize the chamber and the equipment at ambient temperature. DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS in the second, or last, cycle as appropriate.

A minimum of two cycles (a. through h. above) shall be accomplished. If complete determination of compliance with applicable equipment performance standards can be accomplished during each temperature change period of a single cycle, then testing is required during the second cycle only. If the time during a temperature change period does not allow for complete determination of compliance with applicable equipment performance standards, a sufficient number of cycles shall be accomplished so that complete compliance can be determined. When temperature rise induces a potential risk of condensation on the equipment under test, the humidity level of the air in the chamber should be controlled to eliminate this condensation. The test profile is shown graphically in Figure 5-1.

It is permissible to allow additional time with the equipment un-powered at ambient conditions, between the first and second, and subsequent, cycles to accommodate test facility and personnel schedules. Resumption of the second, or subsequent, cycle must be accomplished within 24 hours. No other environmental testing may be performed between cycles.

Note: If this is a combined test, it is not necessary to repeat the Ground Survival Low Temperature, Short-Time Operating Low Temperature, Ground Survival High Temperature, and Short Time Operating High Temperature tests as defined in steps a. and d. above during the second cycle.

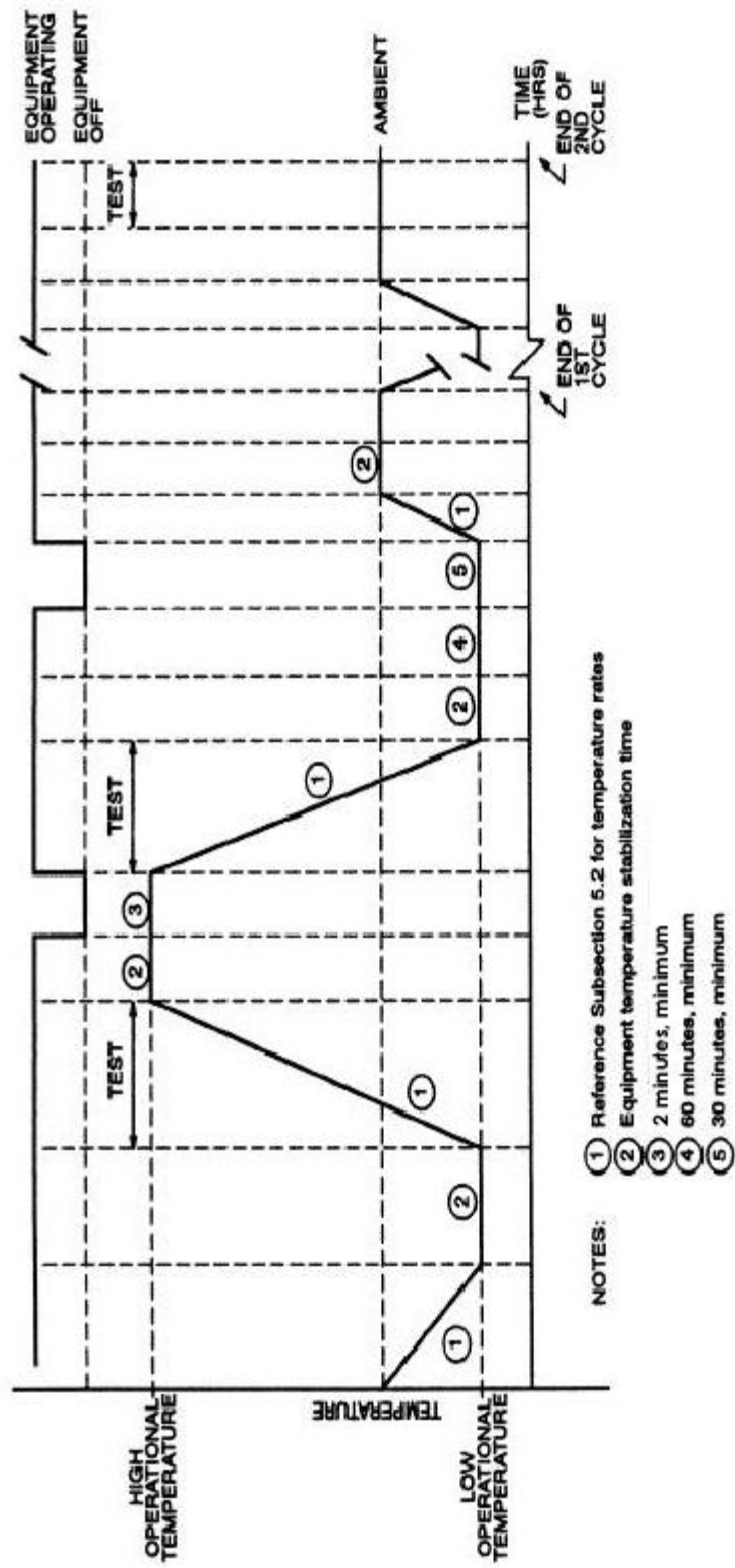


FIGURE 5-1 TEMPERATURE VARIATION TEST

5.3.2 Test Procedure Category S1

The temperature variation test for Category S1 should not be combined with other temperature testing.

The following procedures shall apply:

- a. Commencing at ambient temperature with the equipment operating, lower the temperature in the chamber towards the operating low temperature level at the applicable rates specified in Subsection 5.2.
- b. Stabilize the equipment, if workable, at this operating low temperature level.
- c. Raise the temperature in the chamber towards the operating high temperature at the applicable rates specified in Subsection 5.2. During this temperature change, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.
- d. Stabilize the equipment at the operating high temperature, if workable. Maintain the equipment in a non-operating state for a minimum of 2 minutes.
- e. Turn the equipment on and lower the temperature in the chamber towards the operating low temperature level at the applicable rates specified in Subsection 5.2. During this temperature change DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.
- f. Stabilize the equipment temperature, if workable, with the chamber at the operating low temperature, and continue to operate the equipment for at least one hour. Then turn off the equipment for 30 minutes, and restart the equipment while maintaining the chamber at the operating low temperature.
- g. Change the temperature of the chamber towards the ambient temperature at the applicable rates specified in Subsection 5.2.
- h. Stabilize the chamber and the equipment at ambient temperature, if workable. DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS in the second, or last, cycle as appropriate.

A minimum of two cycles (a. through h. above) shall be accomplished. If complete determination of compliance with applicable equipment performance standards can be accomplished during each temperature change period of a single cycle, then testing is required during the second cycle only. If the time during a temperature change period does not allow for complete determination of compliance with applicable equipment performance standards, a sufficient number of cycles shall be accomplished so that complete compliance can be determined. When temperature rise produces condensation on the equipment tested, the humidity level of the air in the chamber should be controlled to eliminate this condensation.

5.3.3 Test Procedure Category S2

The temperature variation test for Category S2 shall not be combined with other temperature testing.

The required test apparatus shall consist of either one two-celled chamber or two separate chambers in which the test conditions can be established and maintained. Chamber 1 shall be set to the operating low temperature and chamber 2 shall be set to the operating high temperature. The insertion of equipment in test chambers can modify its environmental condition. In this case, the temperature shall be stabilized within five minutes after transfer of the test item.

The following test procedure shall apply:

- a. Place the equipment into chamber 1, and turn the equipment on.
- b. Stabilize the equipment, if workable, at the operating low temperature.
- c. Transfer the equipment from chamber 1 to chamber 2 as rapidly as possible but in no more than five minutes. In the case of when separate chambers are used, it is permissible to turn the equipment on immediately after the equipment transfer. If the transfer requires more than five minutes, it shall be indicated in the qualification form.
- d. Stabilize the equipment at the operating high temperature, if workable. During this temperature stabilization, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.
- e. Turn the equipment off, and keep it in a non operating state for a minimum of 2 minutes
- f. Turn the equipment on, and transfer the equipment from chamber 2 to chamber 1 (from high to low temperature) as rapidly as possible but in no more than five minutes. In the case of when separate chambers are used, it is permissible to turn the equipment on immediately after the equipment transfer. If the transfer requires more than five minutes, it shall be indicated in the Qualification Form
- g. Stabilize the equipment at the operating low temperature, if workable, and continue to operate the equipment for at least one hour. During the temperature stabilization, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.
- h. Turn off the equipment for 30 minutes and restart the equipment while maintaining the chamber 1 at operating low temperature
- i. Transfer the equipment at ambient temperature, and after equipment temperature stabilization, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS in the second, or last, cycle as appropriate.

A minimum of two cycles (a. through i. above) shall be accomplished. If complete determination of compliance with applicable equipment performance standards can be accomplished during each temperature change period of a single cycle, then testing is required during the second cycle only. If the time during a temperature change period does not allow for complete determination of compliance with applicable equipment performance standards, a sufficient number of cycles shall be accomplished so that complete compliance can be determined. When temperature rise induces a potential risk of condensation on the equipment under test, the humidity level of the air in the chamber should be controlled to eliminate this condensation.

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**Environmental Conditions and Test
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Section 6

Humidity

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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6.0 Humidity

6.1 Purpose of the Test

This test determines the ability of the equipment to withstand either natural or induced humid atmospheres. The main adverse effects to be anticipated are:

- a. Corrosion.
- b. Change of equipment characteristics resulting from the absorption of humidity.
For example:
 - Mechanical (metals).
 - Electrical (conductors and insulators).
 - Chemical (hygroscopic elements).
 - Thermal (insulators).

6.2 Equipment Categories

Category A - Standard Humidity Environment

The standard humidity environment ordinarily provides an adequate test environment for equipment intended for installation in civil aircraft, non-civil transport aircraft and other classes, within environmentally controlled compartments of aircraft in which the severe humidity environment is not normally encountered.

Category B - Severe Humidity Environment

Equipment installed in zones not environmentally controlled may be required to be operated under conditions such that it is subjected to a more severe atmospheric humidity environment for periods of time in excess of that specified for the standard humidity environment.

Category C - External Humidity Environment

Equipment may be required to be operated under conditions such that it is subjected to direct contact with outside air for periods of time in excess of that specified for the standard humidity environment.

Subject the equipment to an atmosphere in which the relative humidity (RH) is 95 ± 4 percent (%) RH, unless stated otherwise in the following steps. Moisture shall be provided by steam or by evaporation of water having a percent (pH) value between 6.5 and 7.5 or the water resistivity shall not be less than 250,000 ohm centimeters when measured at 25 degrees Celsius ($^{\circ}\text{C}$). The velocity of air throughout the exposure area shall be between 0.5 and 1.7 meters per second. The test chamber shall be vented to the atmosphere to prevent buildup of pressure, and provisions shall be made to prevent water from dripping onto the equipment.

6.3.1**Category A—Standard Humidity Environment**

The test profile is shown graphically in [Figure 6-1](#). The procedure shall be in accordance with the following steps:

- Step 1:** Install the test item in the test chamber, and ensure its configuration is representative of that used in actual service.
- Step 2:** Stabilize the test item at 38 ± 2 $^{\circ}\text{C}$ and 85 ± 4 % RH.
- Step 3:** Over a two-hour period, ± 10 minutes, raise the chamber temperature to 50 ± 2 $^{\circ}\text{C}$ and humidity to 95 ± 4 % RH.
- Step 4:** Maintain the chamber temperature at 50 ± 2 $^{\circ}\text{C}$ and humidity at 95 ± 4 % RH for six hours minimum.
- Step 5:** During the next 16-hour period, ± 15 minutes, decrease the temperature gradually to 38 ± 2 $^{\circ}\text{C}$ or lower. During this period, keep the humidity as high as possible and do not allow it to fall below 85 % RH.
- Step 6:** Steps 3, 4 and 5 constitute a cycle. Repeat these steps until a total of two cycles (48 hours of exposure) have been completed.
- Step 7:** At the end of the exposure period, remove the equipment from the test chamber and drain off (do not wipe) any condensed moisture. Within one hour after the two cycles are completed, apply normal supply power and turn on the equipment. Allow 15 minutes maximum following the application of primary power for the equipment to warm up. For equipment that does not require electrical power for operation, warm up the equipment for 15 minutes maximum by the application of heat not to exceed the short-time operating high temperature test as required by applicable equipment categories. Immediately following the warm-up period, make such tests and measurements as are necessary to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

6.3.2 Category B—Severe Humidity Environment

The test profile is shown graphically in Figure 6-2. The procedure shall be in accordance with the following steps:

- Step 1:** Install the test item in the test chamber, and ensure its configuration is representative of that used in actual service.
- Step 2:** Stabilize the test item at 38 ± 2 °C and 85 ± 4 % RH.
- Step 3:** Over a two-hour period, ± 10 minutes, raise the chamber temperature to 65 ± 2 °C and humidity to 95 ± 4 % RH.
- Step 4:** Maintain the chamber temperature at 65 ± 2 °C and humidity at 95 ± 4 % RH for six hours minimum.
- Step 5:** During the next 16-hour period, ± 15 minutes, decrease the temperature gradually to 38 ± 2 °C or lower. During this period, keep the humidity as high as possible and do not allow it to fall below 85 % RH.
- Step 6:** Steps 3, 4 and 5 constitute a cycle. Repeat these steps until a total of 10 cycles (240 hours of exposure) have been completed.
- Step 7:** At the end of the exposure period, remove the equipment from the test chamber and drain off (do not wipe) any condensed moisture. Within one hour after the 10 cycles are completed, apply normal supply power and turn on the equipment. Allow 15 minutes maximum following the application of primary power for the equipment to warm up. For equipment that does not require electrical power for operation, warm up the equipment for 15 minutes maximum by the application of heat not to exceed the short-time operating high temperature test as required by applicable equipment categories. Immediately following the warm-up period, make such tests and measurements as are necessary to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

6.3.3 Category C—External Humidity Environment

The test profile is shown graphically in Figure 6-3. The procedure shall be in accordance with the following steps:

- Step 1:** Install the test item in the test chamber, and ensure its configuration is representative of that used in actual service.
- Step 2:** Stabilize the test item at 38 ± 2 °C and 85 ± 4 % RH.
- Step 3:** Over a two-hour period, ± 10 minutes, raise the chamber temperature to 55 ± 2 °C and humidity to 95 ± 4 % RH.

- Step 4:** Maintain the chamber temperature at 55 ± 2 °C and humidity at 95 ± 4 % RH for six hours minimum.
- Step 5:** During the next 16-hour period, ± 15 minutes, decrease the temperature gradually to 38 ± 2 °C or lower. During this period, keep the humidity as high as possible and do not allow it to fall below 85 %.
- Step 6:** Steps 3, 4 and 5 constitute a cycle. Repeat these steps until a total of six cycles (144 hours of exposure) have been completed.
- Step 7:** At the end of the exposure period, remove the equipment from the test chamber and drain off (do not wipe) any condensed moisture. Within one hour after the six cycles are completed, apply normal supply power and turn on the equipment. Allow 15 minutes maximum following the application of primary power for the equipment to warm up. For equipment that does not require electrical power for operation, warm up the equipment for 15 minutes maximum by the application of heat not to exceed the short-time operating high temperature test as required by applicable equipment categories. Immediately following the warm-up period, make such tests and measurements as are necessary to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

6.3.4 Conducting Spot Checks

For conducting spot checks on the performance of the equipment under test, the equipment may be operated at the end of each of the 6 or 10 cycles as appropriate for a period not to exceed 15 minutes. If the equipment is removed from the test chamber to conduct a spot check, the period of removal shall not exceed 20 minutes, and the equipment shall not be operated for more than 15 minutes of this 20-minute period.

6.3.5 Other Specified Checks

If the applicable performance standard requires that other checks be made to determine compliance, these shall also be performed during this test.

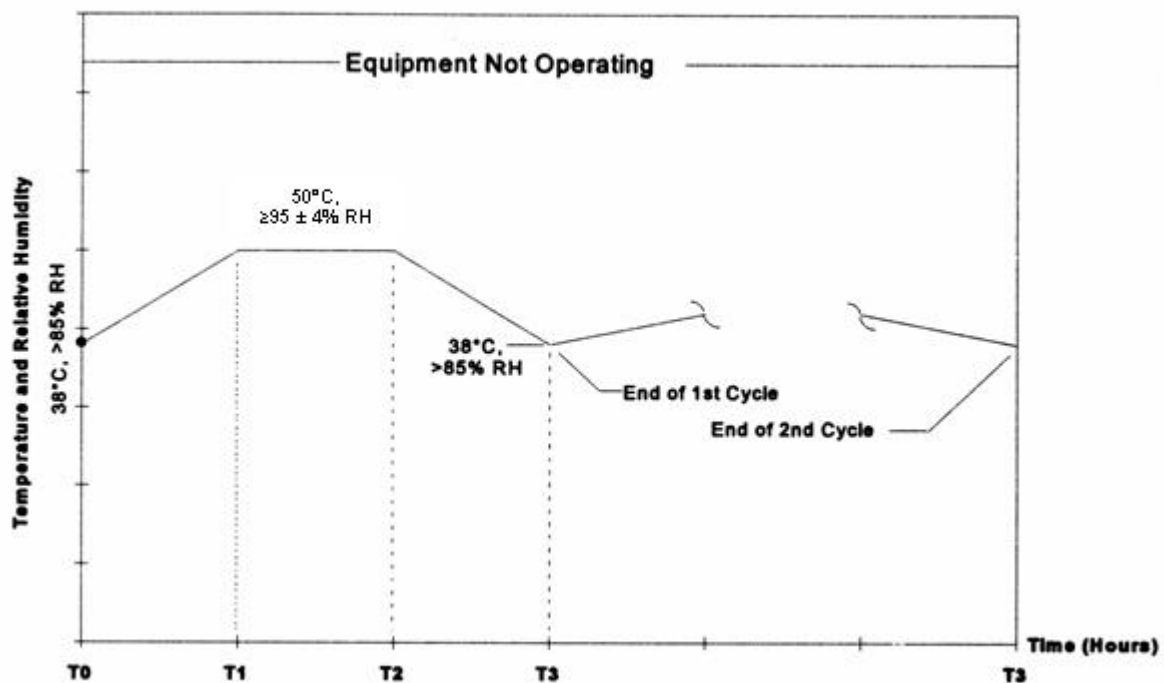


Figure 6-1 Category A - Standard Humidity Environment Test

- NOTES:**
- 1) T0 to T1 is 2 hours ± 10 minutes.
 - 2) T1 to T2 is 6 hours, minimum.
 - 3) T2 to T3 is 16 hours ± 15 minutes. During this period, relative humidity should not fall below 85%.
 - 4) See paragraph 6.3.1, Step 7, for continuation of test after the end of the 2nd cycle.
 - 5) T0 represents the beginning of the subsequent cycle(s), not the initial point of the test.

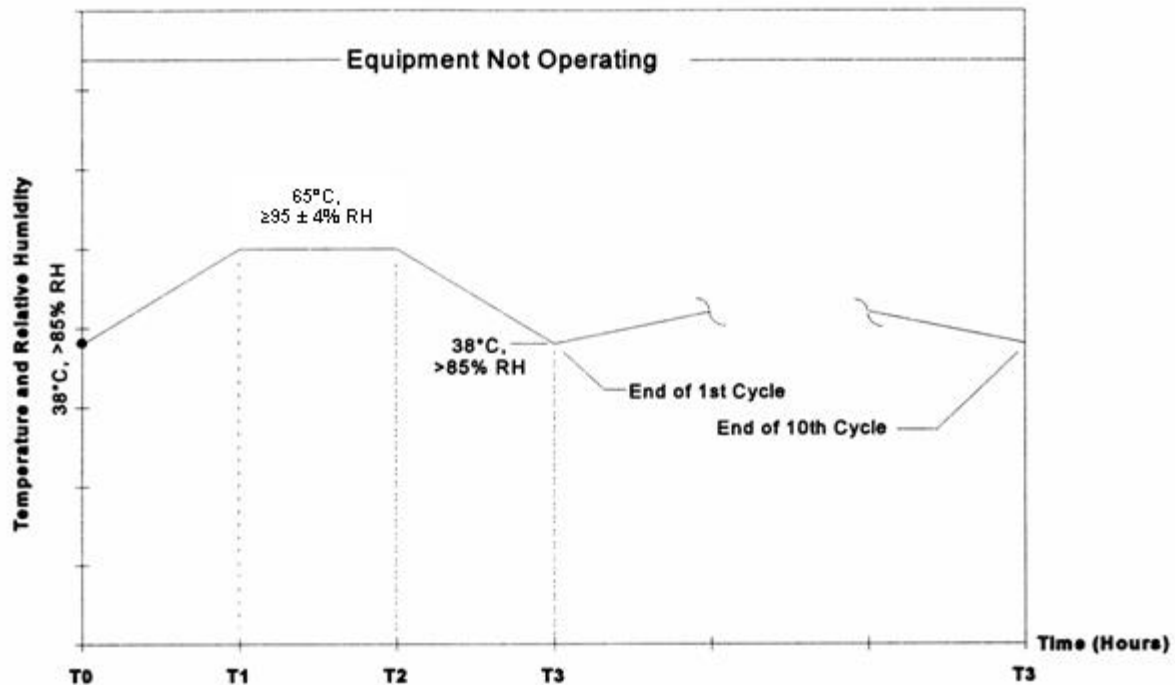


Figure 6-2 Category B - Severe Humidity Environment Test

- NOTES:**
- 1) T0 to T1 is 2 hours ± 10 minutes.
 - 2) T1 to T2 is 6 hours, minimum.
 - 3) T2 to T3 is 16 hours ± 15 minutes. During this period, relative humidity should not fall below 85%.
 - 4) See paragraph 6.3.2, Step 7, for continuation of test after the end of the 10th cycle.
 - 5) T0 represents the beginning of the subsequent cycle(s), not the initial point of the test.

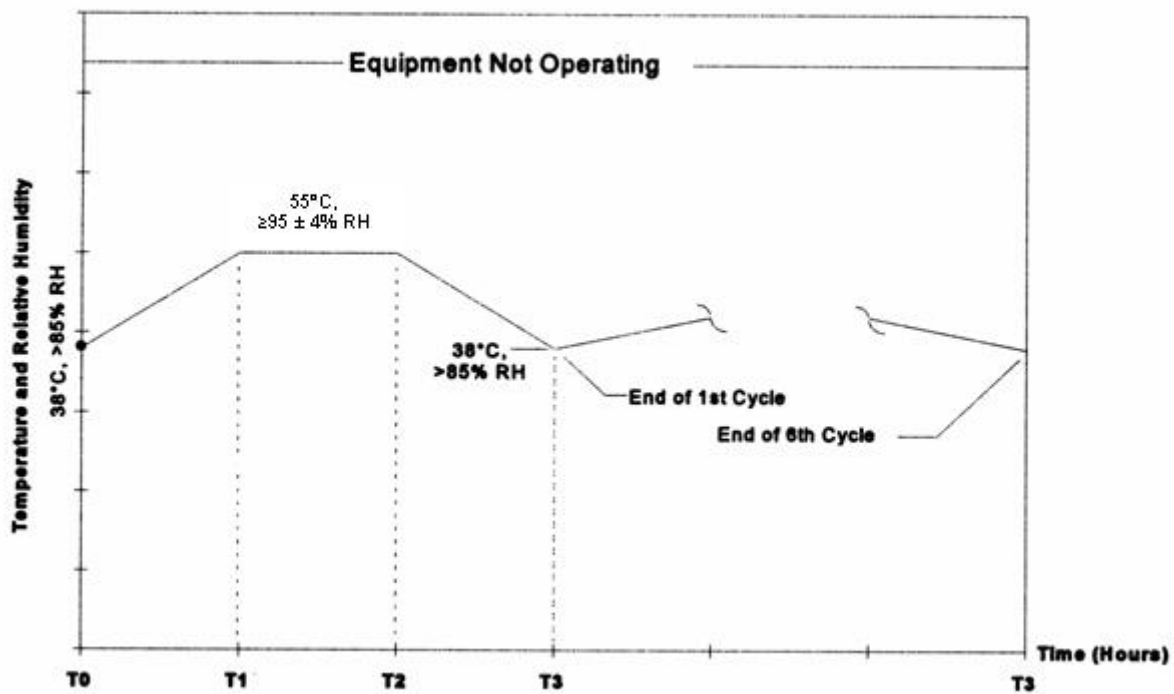


Figure 6-3 Category C - External Humidity Environment Test

- NOTES:**
- 1) T0 to T1 is 2 hours ± 10 minutes.
 - 2) T1 to T2 is 6 hours, minimum.
 - 3) T2 to T3 is 16 hours ± 15 minutes. During this period, relative humidity should not fall below 85%.
 - 4) See paragraph 6.3.3, Step 7, for continuation of test after the end of the 6th cycle.
 - 5) T0 represents the beginning of the subsequent cycle(s), not the initial point of the test.

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 7

Operational Shocks and Crash Safety

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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7.0 Operational Shocks and Crash Safety

7.1 Purpose of the Tests

The operational shock test verifies that the equipment will continue to function within performance standards after exposure to shocks experienced during normal aircraft operations. These shocks may occur during taxiing, landing or when the aircraft encounters sudden gusts in flight. This test applies to all equipment installed on fixed-wing aircraft and helicopters. Two operational shock test curves are provided; a standard 11 ms pulse and a low frequency 20 ms pulse. The 20 ms pulse may not be adequate to test against the effect of longer duration shocks on equipment that have its lowest resonance frequency (as per section 8) below 100Hz. For such equipment, a pulse of 100 ms duration should be considered.

The crash safety test verifies that certain equipment will not detach from its mountings or separate in a manner that presents a hazard during an emergency landing. It applies to equipment installed in compartments and other areas of the aircraft where equipment detached during emergency landing could present a hazard to occupants, fuel systems or emergency evacuation equipment. These tests do not satisfy FAR requirements for all equipment, e.g. seats and seat restraints.

NOTE: For fixed-wing aircraft: a complete installation demonstration, i.e. including aircraft acceleration loads (such as flight maneuvering, gust and landing) in addition to the crash safety loads, may be accomplished by using the "Unknown or Random" orientations for the "sustained" test procedure.

Using a dummy load on the shock test apparatus may be necessary to ensure that the recorded shock pulse will be within the specified tolerances of [Figure 7-2](#).

7.1.1 Equipment Categories

Category A

Equipment tested for standard operational shocks.

Category B

Equipment tested for standard operational shock and crash safety.

Category D

Equipment tested for low-frequency operational shock.

Category E

Equipment tested for low-frequency operational shock and low frequency crash safety.

7.2 Operational Shocks

Performance compliance requirements are normally required following application of the shocks. If equipment requires monitoring during the application of the shock pulses, the monitoring requirements must be stated in the relevant equipment specification.

7.2.1 Test Procedure

Secure the equipment to a shock table by means of a rigid test fixture and mounting means intended for use in service installations. The mounting of the equipment should include those non-structural connections that are a normal part of the installation. The accelerometer used to measure or control the input shock pulse shall be placed as close as practicable to an equipment attachment point. The test system accuracy to measure acceleration shall be within ± 10 percent of standard reading. Unless otherwise stated in the EUT specification, the equipment shall be operating, and its temperature stabilized. Apply to the test item three shocks having a terminal saw-tooth wave shape with an acceleration peak value of six (6) g's in each orientation. The nominal pulse duration shall be 11 ms for standard shock testing and 20 ms for low frequency shock testing. The characteristics of instrumentation used to demonstrate compliance and the shock pulse tolerance limits are shown in Figures 7-1 and 7-2, respectively. An equivalent shock response spectrum may replace the terminal saw-tooth wave shape.

After application of the shocks, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

When using a conventional drop shock machine, the equipment shall be shock tested in the following orientations:

- a. Normal upright.
- b. Suspended upside down.
- c. At orientations such that the first major orthogonal axis of the equipment successively forms angles of +90 degrees and -90 degrees (two orientations) with the plane of the table.
- d. At orientations such that the second major orthogonal axis of the equipment successively forms angles of +90 degrees and -90 degrees (two orientations) with the plane of the table.

7.2.2 Alternate Test Procedure

It is permissible to apply the shocks specified in paragraph 7.2.1 with the equipment mounted in its normal operating orientation (i.e., as spatially oriented in its customary aircraft installation), provided that three shocks are applied in both directions of the three orthogonal axes.

7.3 Crash Safety

If the crash safety test is applicable, both the impulse and sustained test procedures shall be performed.

During the impulse tests of paragraphs 7.3.1, 7.3.2 or 7.3.3, an equivalent weight (dummy load) may be substituted for electrical-mechanical components normally mounted within or on the equipment case. Such equivalent weight shall approximate the weight of the components that it replaces and shall be so located that the center of gravity of the equipment is essentially unchanged. The equivalent weight shall not contribute to the strength of the equipment case or its mounting fastenings to a greater extent than the components it replaces.

7.3.1 Test Procedure 1 (Impulse)

Secure the equipment or dummy load to a shock table by means of a rigid test fixture and mounting means intended for use in service installations.

In each of the six equipment orientations listed in paragraph 7.2.1, apply one 20 g shock having a wave shape identical to that specified in Figures 7-1 and 7-2. After application of the six shocks, bending and distortion shall be permitted. There shall be no failure of the mounting attachment and the equipment or dummy load shall remain in place.

7.3.2 Alternate Test Procedure (Impulse)

It is permissible to apply the shocks specified in paragraph 7.3.1 with the equipment mounted in its normal operating orientation provided that these shocks are applied in both directions of the three (3) orthogonal axes.

7.3.3 Test Procedure 2 (Sustained)

It is expected that the sustained test procedure below will normally be carried out using a centrifuge or sled. In certain cases, however, it is acceptable to simulate the effects of inertia by applying forces statically through the center of gravity of the equipment under test, providing it can be determined that other parts within the equipment can be contained within the casing of the equipment should they break loose.

Secure the equipment or dummy load to test facility by means of a rigid test fixture and mounting means intended for use in service installation. Apply the appropriate test loads for a minimum of three seconds in each direction of load. "Direction of load" in [Table 7-1](#) applies to the aircraft's major orthogonal axes. The applicable test levels are given in [Table 7-1](#) (*). Where the orientation of the equipment to the aircraft axes is known, then the required load and direction of load relative to the equipment can be determined. The airplane directions together with the definitions regarding a centrifuge test are provided on Figure 7-3. If the orientation of the equipment under test is unknown or not fixed in relation to the aircraft axes, then the random orientation is required along each direction of the equipment's three orthogonal axes as defined in [Table 7-1](#). After application of the six loads, bending and distortion shall be permitted. There shall be no failure of the mounting attachment and the equipment or dummy load shall remain in place.

The crash safety load requirements represent inertia load requirements, with the loads being in the same direction as the g's. If a static test were used to demonstrate compliance, the load would be applied in the same direction as the g requirement. If a centrifuge is used, the loads are opposite the direction of the acceleration. In order to simulate the inertia loads doing a centrifuge test, the equipment must be oriented such that the loads are in the correct direction, not the acceleration. For instance, for a 9 g Forward test, the front end of the equipment shall face opposite the center of the centrifuge. That would simulate the inertia loads the equipment would see for the Forward 9g condition.

Aircraft Type	Test Type (5)	Sustained Test Acceleration (g Minimum)				
		Direction of Load (Aircraft Direction)				
		Up	Down	Forward	Aft	Side (4)
1. Helicopters (1)	F	4.0	20.0	16.0	NA	8.0
	R	20.0	20.0	20.0	20.0	20.0
2. Fixed-Wing Transport (2)	F	3.0	6.0	9.0	1.5	4.0
	R	9.0	9.0	9.0	9.0	9.0
3. Fixed-Wing Non-Transport (3)	F	3.0	NA	18.0	NA	4.5
	R	18.0	18	18.0	18.0	18.0
4. All Fixed-Wing	F	3.0	6.0	18.0	1.5	4.5
	R	18.0	18	18.0	18.0	18.0
5. Helicopter and All Fixed-Wing	F	4.0	20.0	18.0	1.5	8.0
	R	20.0	20.0	20.0	20.0	20.0

NOTES: (1) Reference FAR 27.561

(2) Reference FAR 25.561

(3) Reference FAR 23.561

(4) Side includes both left and right directions

(5) "F" is known and Fixed orientation. "R" is unknown or Random orientation.

Table 7-1 Crash Safety Sustained Test Levels

* **CAUTION:** These test levels may not satisfy the installation requirement in the FARs.

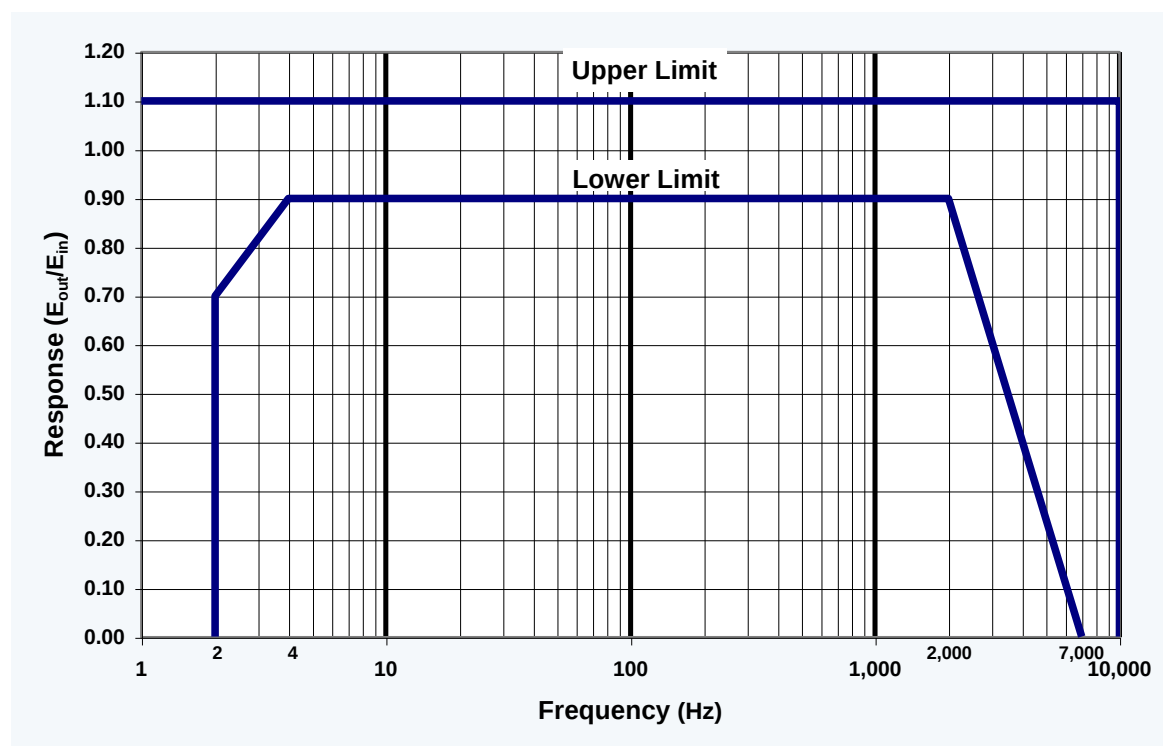
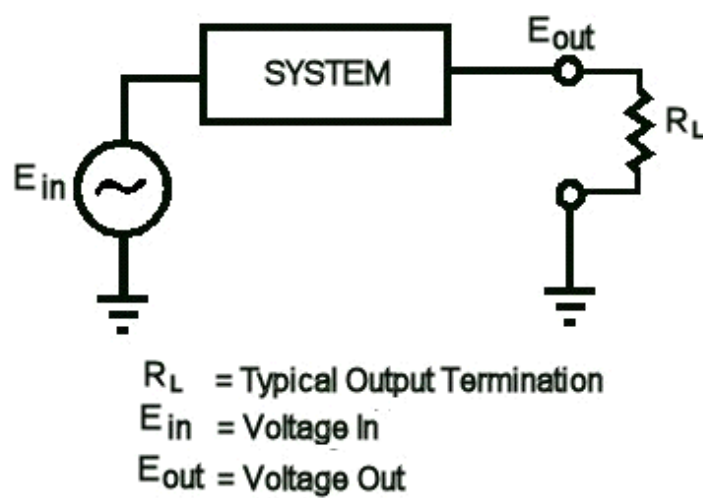
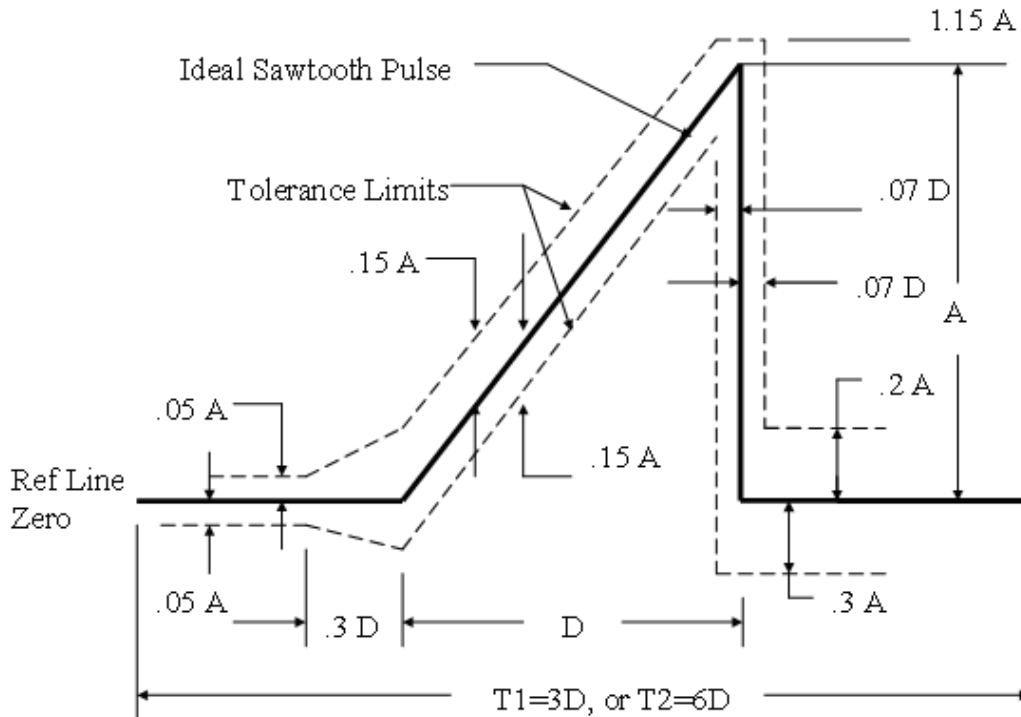


Figure 7-1 Shock Measuring System Frequency Response

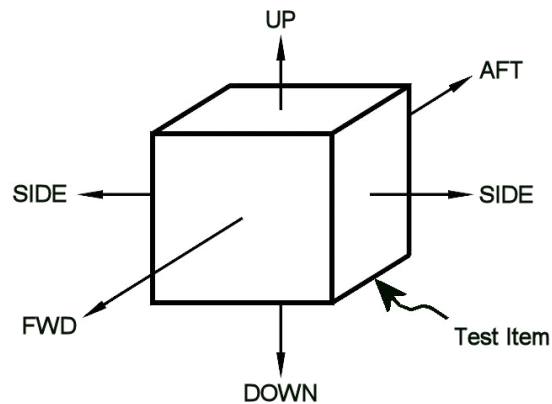


- D = Duration of nominal pulse.
 A = Peak acceleration of nominal pulse.
 T_1 = Minimum time during which the pulse shall be monitored for shocks produced using a conventional shock testing machine.
 T_2 = Minimum time during which the pulse shall be monitored for shocks produced using a vibration generator.

Test (impulse)	Peak value (A) (g)	Nominal duration (D) (ms)
Standard operational	6	11
Low-frequency operational	6	20
Crash safety	20	11
Low frequency Crash safety	20	20

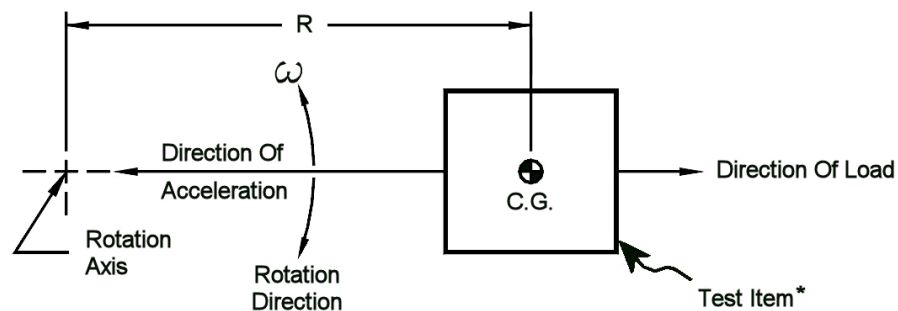
NOTE: The oscillogram shall include a time duration T_1 or T_2 with a pulse located approximately in the center. The acceleration amplitude of the terminal saw-tooth pulse is A and its duration is D . The measured acceleration pulse shall be contained within the dashed line boundaries and the measured velocity change (which may be obtained by integration of the acceleration pulse) shall be within the limits $V_i \pm 0.1 V_i$, where V_i is the velocity change associated with the ideal pulse which equals $0.5 DA$. The integration to determine velocity change shall extend from $0.4 D$ before the pulse to $0.1 D$ after the pulse.

Figure 7-2 Terminal Saw Tooth Shock Pulse Configuration & Its Tolerance Limits



Aircraft Directions

Note: If a centrifuge is used, the effects of rotational acceleration and rate of acceleration on the specimen should be considered.



Looking Down On The Plane of Rotation

- * Align test item so the aircraft direction aligns with “direction of load”, and apply the test acceleration specified for that aircraft direction.

$$\text{Acceleration (G's)} = \frac{R(\omega)^2}{9.81} = 0.001118 * R * (\text{RPM})^2$$

R = Radius, Meters

ω = Angular Rotation, Radians/Second

RPM = Revolutions Per Minute

Centrifuge Definitions

Figure 7-3 Definitions for Crash Safety Sustained Test

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 8

Vibration

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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8.0 VIBRATION

8.1 Purpose of the Tests

These tests demonstrate that the equipment complies with the applicable equipment performance standards (including durability requirements) when subjected to vibration levels specified for the appropriate installation.

8.2 Applicability

The vibration tests described below apply to equipment installed on fixed-wing propeller aircraft, fixed-wing turbojet, turbofan, and propfan aircraft and helicopters.

The specific vibration tests to be performed to show compliance with the performance standards are defined in this paragraph and are dependent upon three identifiers: (1) aircraft type, (2) test category and (3) aircraft zone location. The requirements and procedures to accomplish these tests are specified in subsequent paragraphs herein.

8.2.1 Vibration Test Category Definitions

The appropriate category (or categories) selected from the categories defined below should be based upon the level of assurance required for the equipment's demonstration of performance. For equipment on fixed wing aircraft, either a standard or a robust vibration test may be performed. The need to do the high level short duration test is dependent upon the equipment performance requirements. For equipment on helicopters, only a robust test may be performed.

8.2.1.1 Standard Vibration Test (Category S)

The standard vibration test for fixed wing aircraft demonstrates that equipment will meet its functional performance requirements in the vibration environment experienced during normal operating conditions of the aircraft.

8.2.1.2 Robust Vibration Test (Categories R, U, U2)

The robust vibration test demonstrates that equipment will operate satisfactorily while being subjected to vibration and that it will continue to operate satisfactorily after being subjected to endurance vibration levels. It combines a demonstration of the equipment functional performance and structural integrity. This test should be performed on all equipment where resistance to effects of long duration exposure to vibration must be demonstrated. The necessity for conducting this test in lieu of the standard vibration test shall be determined by the relevant equipment specification. Categories U and U2 are for equipment to be installed in helicopters with unknown rotor related frequencies. The robust test may or may not represent a service life test. A service life test depends on the vibration environment the equipment is subjected to relative to the test levels. If the vibration environment is known, and the relevant equipment specification requires a service life test, the robust test can be made to represent a service life test by adjusting the test levels and/or the test times using accepted fatigue scaling relationships.

8.2.1.3 High-Level, Short Duration Vibration Test (Categories H, Z)

High-level short duration transient vibration levels are encountered during abnormal fixed wing aircraft vibration conditions that occur during an engine fan blade loss. This test should be applied to equipment in which a functional loss of performance can hazardously affect the aircraft's performance. The Category H test is a generalized test

that encompasses all applications. The Category Z test covers restricted low fan frequency applications. These tests do not replace the standard or robust tests. Also see following **CAUTION** note.

CAUTION: A full analysis of vibration levels related to some specific engine imbalance conditions has not been evaluated against these limits. Therefore this test alone may not be sufficient for some applications without additional test or analysis.

8.2.2 Test Curve / Test Level Selection

8.2.2.1 Test Description

The data in Table 8-0 below provides a brief description of the test for each of the test categories. See the procedures for a more detailed description.

Table 8-0 Test Description

Category	Aircraft Type	Standard Vibration	High Level - Short Duration Vibration	Robust Vibration
S	Fixed-Wing	1 Hr/Axis sine or random at perf. Level	NA	NA
H or Z	Fixed-Wing	NA	High g / low f sine sweep each axis	NA
R	Fixed-Wing	NA	NA	Sine of 3 Hrs/Axis less 30 min/dwell (max 4 dwells) or Random at perf. Level (minimum of 10 minutes) and 3 Hrs Endurance level (repeat in all 3 axes)
R or U	Helicopter	NA	NA	Sine-On-Random; 2 Hrs at Endurance levels plus dwells (max of 4 dwells, max of 3 hours total test time) and performance test (minimum of 10 minutes) at beginning and end of test period (repeat in all 3 axes). Test repeated 3 times for Category U.
U2	Helicopter	NA	NA	Random ; performance test at beginning and end of test period (minimum of 10 minutes), 3 hrs at Endurance level (repeat in all 3 axes)

8.2.2.2 Test Curves

Table 8-1 specifies the appropriate test curves to be used for the applicable category and aircraft zone for each aircraft type. The test levels for the categories of Table 8-1 are

shown in Figures 8-1 to 8-5 for fixed-wing aircraft and Tables 8-2a and 8-2b for helicopters.

Note that the zone for "instrument panel, console and racks" includes interior items attached to the galley interior partitions and cabin floor and is separate from the "fuselage" zone. The "fuselage" zone applies to all equipment not installed in multiple slot equipment racks but that is attached to frames, stringers, skin and other fuselage structure or brackets.

Weight Allowance – For equipment items weighing greater than 22.7kg (50 lbs), a reduction in standard and robust test levels for frequencies above 60 Hz is allowed using the following schedule: The random and sinusoidal standard and robust test levels may be reduced by 0.10 dB for each 0.454 kg (1.0 lb) equipment weight increment above 22.7 kg (50 lb) to a maximum reduction of 6.0 dB. (Note that a 6.0 dB reduction would reduce the APSD level to 1/4 and the sinusoidal level to 1/2 of the original level.)

8.3 Vibration Test Requirements

The following general requirements apply for all vibration tests:

- a. Install the equipment under test so the input vibratory motion is parallel to one of its three major orthogonal axes. Any test fixture used shall be as rigid and symmetrical as practicable. The equipment shall be attached to the fixture or vibration table by the means specified in the equipment specification. Equipment that is mounted on external vibration/shock isolators shall be tested with the isolators.
- b. Where applicable, accelerometers shall be attached to the equipment item undergoing vibration to measure and record the equipment's vibration response in the axis of vibration to determine resonant frequencies and amplification factors. Locations selected may include principal structure, printed circuit boards, large components and modules, where practicable.
- c. The control accelerometer(s) shall be attached to the test fixture as near as practicable to the equipment mounting location for each axis of test. When more than one accelerometer is employed for test level control, the average of the accelerometer control signals for sinusoidal tests or the average of the acceleration power spectral densities (APSD's) for random tests shall be used as the test level control. For all vibration input types, spectrum or APSD plots as appropriate shall be made to demonstrate that the control levels meet the test level requirements.
- d. The random vibration signal should have a Gaussian distribution, and the instantaneous vibration acceleration peaks of the control signal may be limited to three times the g rms acceleration level.
- e. The accuracy of the instrumentation system for measuring sinusoidal acceleration shall be ± 10 percent for acceleration and ± 2 percent for frequency.
- f. If the random vibration test requirements exceed the power capability of the vibration test system, the test may be performed in separate frequency bands of 10 to 600 Hz and 600 to 2000 Hz. The specified test time shall be applied to each frequency band.

8.4 Vibration Test Level Requirements

8.4.1 Control Level Tolerance Requirements

8.4.1.1 Sinusoidal Control Input

The acceleration test level control, as defined in 8.3c, for any sinusoidal input curve, shall be within ± 10 percent of the specified level over the specified frequency range.

8.4.1.2 Random Control Input

The acceleration power spectral density (APSD) of the test control signal, as defined in 8.3c, shall not deviate from the specified requirements by more than +3 dB or -1.5 dB below 500 Hz and ± 3.0 dB from 500 to 2,000 Hz. The overall g rms level of the control signal shall be within +20 and -5 percent of the overall rms value for the specified APSD curve.

8.4.2 Measurement of Acceleration Power Spectral Density

Analysis and control systems shall use a bandwidth-time (BT) product greater than or equal to 50. Specific analyzer characteristics or their equivalent shall be as specified below. Discrete FFT analysis methods are preferred for APSD measurements.

8.4.2.1 Analog Analyzer Requirements

- a. On-line contiguous filter, equalization/analysis system having a bandwidth, B, less than or equal to 50 Hz.
- b. Swept frequency analysis systems characterized as follows:
 - (1) Constant bandwidth analyzer.
 - (a) Filter bandwidths.
 $B = 10$ Hz, maximum from 10 to 200 Hz. $B = 50$ Hz, maximum from 200 to 2,000 Hz.
 - (b) Analyzer averaging time = $T = 2\tau = 1$ s minimum, where T = true averaging time and τ = analyzer time constant.
 - (c) Analysis linear sweep rate = $R = B/4\tau$ or $B^2/8$ Hz/s maximum, whichever is smaller.
 - (2) Constant percentage bandwidth analyzer.
 - (a) Filter bandwidth = Pf_C = one third octave maximum. (where P = percentage ≤ 0.23 and f_C = analyzer center frequency).
 - (b) Analyzer averaging time = $T = 50/Pf_C$ minimum.
 - (c) Analysis logarithmic sweep rate = R.

$$R = \frac{Pf_c}{4\tau} \text{ or } \frac{(Pf_c)^2}{8} \text{ Hz/s maximum, whichever is smaller}$$

8.4.2.2 Digital Analyzer Requirements

Digital power spectral density analysis system employing discrete frequency analysis techniques shall have a minimum of 400 lines of frequency resolution (i.e., Δf equal to or less than five Hz). The bandwidth-time product is equal to the number of records used to obtain one APSD (i.e., the number of ensemble averages should be 50 or greater when measuring an APSD).

8.5 Standard Vibration Test Procedure-Fixed Wing Aircraft

The standard vibration test curves in [Table 8-1](#) to be used for the specified category and zone are given in [Figures 8-1](#) through [8-3](#). For most aircraft type / zone applications either a sinusoidal or a random test vibration curve is defined. For Aircraft Type 6 Zone 7, the user can choose between sinusoidal and random vibration testing. The procedures for both sinusoidal and random tests are defined below. (note: only the applicable sinusoidal or random test needs to be performed).

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS DURING AND AT THE CONCLUSION OF STANDARD VIBRATION TESTING.

8.5.1 Sinusoidal Test Procedure

In each of the equipment's three orthogonal axes perform the following tests using the appropriate test curves of [Figure 8-2](#) or [Figure 8-3](#).

With the equipment operating, perform sine frequency sweep cycles varying the vibration frequency over the appropriate frequency range from lowest to the highest (up-sweep) to the lowest (down-sweep) specified frequencies with a logarithmic sweep rate not exceeding 1.0 octave/minute. During the initial up-sweeps, record plots of the accelerometers at the response locations selected and identify the critical frequencies. Critical frequencies are defined as those frequencies where: (1) mechanical vibration resonances have peak acceleration amplitudes greater than twice the input acceleration amplitude, or (2) a change in performance or behavior is noticeable whether or not performance standards are exceeded.

Continue the vibration sine frequency sweep cycling and operation for one hour minimum to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Any changes in the critical frequencies that occur during the test shall be noted on the Environmental Qualification Form (see [Appendix A](#)). At the completion of the test, the equipment shall be inspected and shall show no evidence of structural failure of any internal or external component.

Any difficulty in reading any display feature of the test item, when the total displacement of applied input vibration exceeds 0.5 mm, shall not be a cause for failing the test.

8.5.2 Random Test Procedure

In each of the equipment's three orthogonal axes, perform the following test sequence:

- a. With the equipment not operating, perform a 0.5 g-PK sinusoidal scan from 10 Hz to 2000Hz at a sweep rate not exceeding 1.0 octave/minute. Record plots of response accelerometers at selected position on the equipment to determine resonant frequencies and amplification factors. Resonant frequencies are defined as response peaks that are greater than twice the input acceleration amplitude.
- b. With the equipment operating, apply the appropriate performance level test APSD of Figure 8-1 for a minimum of one-hour-per-axis to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. During this vibration period, also perform an APSD analysis of the vibration response measurements on the equipment.
- c. Repeat the sinusoidal scan of subparagraph 8.5.2.a. Any changes in vibration resonant frequencies shall be noted on the environmental Qualification form (see Appendix A).

At the completion of the test, the equipment shall be inspected and shall show no evidence of structural failure of any internal or external component.

8.6 High-Level, Short Duration Vibration Test Procedure

With the equipment operating, apply sinusoidal vibration at the levels shown in Figure 8-5 for the appropriate equipment zone location. For general Category H applications, perform one sinusoidal linear frequency sweep in each of the equipment's three orthogonal axes from 10 to 250 Hz at a sweep rate not to exceed 0.167 Hz/sec. For restricted Category Z applications, the maximum frequency can be reduced. For this application, the maximum frequency shall be equal to or greater than 2 times the maximum fan rotor speed. For Category Z, the maximum frequency tested shall be reported on the Environmental Qualification Form (see Appendix A). DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARD. Operational performance requirements during and after the test shall be defined by the equipment specification.

8.7 Robust Vibration Test Procedure-Fixed-Wing Aircraft

The robust vibration test curves in Table 8-1 to be used for the specified category and zone location are given in Figure 8-1 to Figure 8-4. For most aircraft type / zone applications either a sinusoidal or a random vibration curve is defined. For Aircraft Type 6 Zone 7, the user can choose between sinusoidal and random vibration tests. The procedures for both sinusoidal and random tests are defined below. (note: only the sinusoidal or random test needs to be performed).

8.7.1 Sinusoidal Test Procedure

In each of the equipment's three orthogonal axes, perform the following test using the appropriate sinusoidal test levels of Figure 8-2.

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS DURING AND AT THE CONCLUSION OF VIBRATION TESTING.

- a. With the equipment operating, unless otherwise specified in the equipment specification, perform sine frequency sweep cycles, varying the vibration frequency over the appropriate frequency range from the lowest to the highest (up-sweep) to the lowest (down-sweep) specified frequencies with a logarithmic sweep rate not exceeding 1.0 octave/minute. The time spent performing these sweeps may be included in the total sweep time of subparagraph 8.7.1.c. During the initial up-sweeps, record plots of the accelerometers at the selected response locations and identify the critical frequencies. Critical frequencies are defined as those frequencies where: (1) mechanical vibration resonance have peak acceleration amplitudes greater than twice the input acceleration amplitude, or (2) a change in performance or behaviour is noticeable whether or not performance standards are exceeded.
- b. Select the four most severe frequencies from the critical frequencies identified in 8.7.1a. Dwell at each of these selected frequencies for 30 minutes. During each resonance dwell, the applied frequency shall be adjusted, if necessary, to maintain the maximum acceleration response at the vibration resonance being dwelled. If fewer than four critical frequencies are identified, dwell at each one for a 30-minute period. If no critical frequencies are identified, then no dwells need be performed.
- c. Following the vibration dwell test, complete the vibration testing by sine frequency sweep cycling. The time spent at frequency cycling will be three hours minus any time spent at testing resonances in 8.7.1.b.

Any changes in the critical frequencies that occur during the test shall be noted on the Environmental Qualification Form (see Appendix A). If no change occurs, a statement to that effect shall be included in the declaration. Any difficulty in reading any display feature of the test item, when the total excursion of applied input vibration exceeds 0.5 mm, shall not be a cause for failing the test.

- d. At the completion of the tests, the equipment shall be inspected and shall show no evidence of structural failure of any internal or external component.

8.7.2

Random Test Procedure

In each of the equipment's three orthogonal axes, perform the following test sequence:

- a. With the equipment not operating, perform a 0.5 g-PK sinusoidal scan from 10 Hz to 2000Hz at a sweep rate not exceeding 1.0 octave/minute. Record plots of response accelerometers at selected position on the equipment to determine resonant frequencies and amplification factors. Resonant frequencies are defined as response peaks that are greater than twice the input acceleration amplitude.
- b. With the equipment operating, apply the appropriate performance level test APSD of Figure 8-1 for the duration necessary (minimum of 10 minutes) to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. During this vibration period, also perform an APSD analysis of the vibration response measurements on the equipment.
- c. Apply the appropriate endurance level test APSD of Figure 8-4 for three hours. Unless otherwise defined in the equipment specification, the test item shall be operating during vibration. Near the beginning and again near the end of the vibration period, perform an APSD analysis of the vibration response measurements on the equipment and DETERMINE COMPLIANCE WITH

APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. If the test item is not operating during the endurance level vibration test, testing to show compliance with the applicable equipment performance standards shall be performed per 8.7.2b above following completion of the endurance level vibration test.

- d. Repeat the sinusoidal scan of subparagraph 8.7.2.a. Any changes in vibration resonant frequencies shall be noted on the environmental Qualification form (see Appendix A).
- e. At the completion of the tests, the equipment shall be inspected and shall show no evidence of structural failure of any internal or external component.

8.8 Vibration Test for Helicopters

The tests described herein are default tests that can be performed on equipment installed on helicopters in which no measured vibration data is available. For helicopters where data have been measured, "tailored" tests may be applied using accepted standard procedures for helicopter test standards. The test procedures cover both known and unknown helicopter frequency cases. For the unknown helicopter frequency case, two optional procedures are provided.

8.8.1 Sine-on-Random Test Procedure – Known Helicopter Frequencies

The test frequencies, test levels and test procedure for performing a sine-on-random vibration test are defined below. Equipment that have passed the test are considered qualified for installation on any helicopter whose frequencies as defined in Table 8-2a are included in the Sine Frequency ranges $f_n \cdot 0.90$ to $f_n \cdot 1.10$ defined in 8.8.1.3.

8.8.1.1 Test Frequencies

The one-per-revolution frequencies of the four primary rotational sources are defined as:

FM = Main rotor one/rev frequency, Hz
 FT = Tail rotor one/rev frequency, Hz
 FE = Engine one/rev frequency, Hz
 FG = Main gearbox one/rev frequency, Hz

The blade passage frequencies of the rotor blades are defined using the number of blades for the main and tail rotors:

NM = Number of blades on the main rotor
 $NM \cdot FM$ = First blade passage main rotor frequency, Hz
 NT = Number of blades on the tail rotor
 $NT \cdot FT$ = First blade passage tail rotor frequency, Hz

The test frequencies to be used for each helicopter zone can be determined using the formulae provided in Table 8-2a.

8.8.1.2 Sine and Random Test Levels

Using the appropriate sinusoidal test frequencies as determined in 8.8.1.1, the sinusoidal test levels, A_n , can be calculated for each frequency from the formulae given in Table 8-

2b. The random levels are also given in Table 8-2b. The combined sinusoidal and random curves appear (generically) as a total test curve in [Figure 8-6](#).

8.8.1.3 Procedure

The applied controlled input vibration level shall have a frequency content of the sum of the sinusoidal frequencies and the wide-band random test levels determined above.

The sinusoidal frequencies shall be varied at a logarithmic sweep rate not exceeding 1 Oct/min from $f_n \cdot (0.9)$ to $f_n \cdot (1.1)$ (where f_n are the sinusoidal frequencies of the test spectrum).

A performance and endurance vibration test shall be performed in each of the equipment's three orthogonal axes using the test procedure defined below.

- a. With the equipment not operating, perform a 0.5 g-PK sinusoidal scan from 10 Hz to 2000Hz at a sweep rate not exceeding 1.0 octave/minute. Record plots of response accelerometers at selected position on the equipment to determine resonant frequencies and amplification factors. Resonant frequencies are defined as response peaks that are greater than twice the input acceleration amplitude.
- b. With the equipment operating, apply the appropriate performance test level curve of [Table 8-1](#) as defined by Tables 8-2a and 8-2b for the duration necessary (minimum of 10 minutes) to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS DURING VIBRATION.
- c. With the equipment operating, unless otherwise specified in the applicable equipment specification, apply the appropriate endurance test level curve of [Table 8-1](#) as defined by Tables 8-2a and 8-2b for a minimum of 2 hours. If one or several of the equipment resonant frequencies determined in 8.8.1.3a are within the +/- 10% bandwidth of the sinusoidal test frequencies, select the most severe frequencies (maximum of 4). Perform sinusoidal dwells at each of these frequencies for 30 minutes. The dwell tests may include multiple frequencies. During each resonance dwell, each of the applied frequencies shall be adjusted, if necessary, to maintain the maximum acceleration response at the resonance being dwelled. The maximum required test time at the endurance levels is 3 hours. If more than two resonances are found, the standard minimum test time of 2 hours may be reduced to keep the total endurance test time from exceeding three hours.
- d. After completion of 8.8.1.3.c, repeat the test of subparagraph 8.8.1.3.b. Any change in the performance shall be noted on the Environmental Qualification Form (see [Appendix A](#)).
- e. Repeat the sinusoidal scan of subparagraph 8.8.1.3.a. Any changes in vibration resonant frequencies shall be noted on the Environmental Qualification Form (see [Appendix A](#)). If no change occurs, a statement to that effect shall be included in the declaration. Any difficulty in reading any display feature of the test item, when the total excursion of applied input vibration exceed 0.5 mm, shall not be a cause for failing the test.
- f. At the completion of the tests, the equipment shall be inspected and shall show no evidence of structural failure of any internal or external component.

8.8.2 Sine-on-Random Test Procedure for Category U – Unknown Helicopter Frequencies

This unknown helicopter frequency test procedure utilizes the known helicopter frequency sine-on-random test procedures of 8.8.1 with the test frequencies being as defined below. The following test sequence may be applied to Table 8-2a Zone 1a and Zone 2 equipment only. This includes the fuselage, instrument panel, console and equipment rack.

Perform three tests per 8.8.1.3 (the tests may be performed using 1, 2 or 3 units) using the following values for the sinusoidal test frequencies:

Test 1: $f_1 = 11$ Hz, $f_2 = 19.9$, $f_3 = 35.5$, $f_4 = 63.9$

Test 2: $f_1 = 13.4$ Hz, $f_2 = 24$, $f_3 = 43.4$, $f_4 = 77.8$

Test 3: $f_1 = 16.3$ Hz, $f_2 = 29.2$, $f_3 = 52.5$, $f_4 = 94.9$

The equipment resonance sine dwells can be done on any one of the tests / test units.

8.8.3 Random Test Procedure for Category U2 – Unknown Helicopter Frequencies

The following random test procedure may be used as an alternate to the sine-on-random test procedure of 8.8.2 for Table 8-2A Zone 1a and Zone 2 equipment. It may also be used for Zone 1b (tail boom) equipment.

In each of the equipment's 3 orthogonal axes, perform the following tests using the test curve and test levels of Figure 8-7.

- a. With the equipment operating, apply the performance level test ASPD for the duration necessary (minimum of 10 minutes) to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS DURING VIBRATION.

During this time period, also perform an ASPD analysis of the vibration acceleration response at selected positions on the equipment.

- b. With the equipment operating, unless otherwise specified in the applicable equipment specification, apply the endurance level test ASPD for 3 hours.
- c. After the three hour test, repeat the test of subparagraph 8.8.3.a. Any change in the performance or the vibration resonance's shall be noted on the Environmental Qualification Form (see Appendix A).
- d. At the completion of the tests, the equipment shall be inspected and there shall be no evidence of structural failure of any internal or external component.

AIRCRAFT TYPE	TEST CATEGORY	AIRCRAFT ZONE						
		1	2	3	4	5	6	7
		FUSELAGE	INSTRUMENT PANEL, CONSOLE & EQUIPMENT RACK	NACELLE & PYLON	ENGINE & GEAR BOX	WING & WHEEL WELL	LANDING GEAR	EMPENNAGE & Fin Tip
1. <u>Helicopters</u> (Reciprocating & Turbojet Engines)	R or U (1)	G	G	H	I			J
	U2 (1)	F & F1	F & F1					
2. <u>Fixed Wing Turbojet or Turbofan Engines</u> (Subsonic & Supersonic)	S	C (3)	B, B2 or B3 (4)	D	W	E	W	E
	H or Z	R	R	P	P	P	P	P
	R	C & C1 (3)	B & B1 or B2 & B12, or B3 & B4 (4)	D & D1	W	E & E1	W	E & E1
3. <u>Fixed Wing Reciprocating & Turboprop Engines Multi Eng over 5,700 KG (12,500 lbs)</u>	S	L(3)	M	T	U	T		
4. <u>Multi Eng Less than 5,700 KG (12,500 lbs)</u>	S	M(3)	M	L	L	L		
5. <u>Single Eng Less than 5,700 KG (12,500 lbs)</u>	S	M	M	M	L	M		
6. <u>Fixed Wing Unducted Turbofan Engines</u> (Propfan)	S	Y (3)	B, B2 or B3 (4)	D	W	E	W	E or Z
	H or Z	R	R	P	P	P	P	P
	R	Y (3)	B & B1 or B2 & B12 or B3 & B4 (4)	D & D1	W	E & E1	W	E & E1 or Z

- NOTES:**
1. U applies to zones 1a and 2 only: (1a is fuselage - 1b is tail boom). U2 is an alternate to U and applies to 1a, 1b and 2 only
 2. Curves B to E are random; curves G to J are Sine-on-Random; all others are sinusoidal.
 3. Does not include equipment mounted on structure directly affected by jet efflux.
 4. Curves B2 and B12 are the same as those found in EUROCAE ED-14C/RTCA DO-160C as B and B', respectively. They are representative of levels expected on many fixed wing aircraft but are not sufficient for many others. Curves B and B1 contain higher levels and reflect the expected environment for all cases. Curves B3 and B4 are representative of large aircraft.

Table 8-1 Categorization and Vibration Tests by Aircraft Types and Equipment Locations

Table 8-2a Sine-on-Random Vibration Test Frequencies for Helicopters

Helicopter Zone Vibration Test Frequencies						
Zone / Test Curve	1a / G	1b / G	2 / G	3 / H	4 / I	7 / J
(1) Test Frequencies f_n	Fuselage	Tail boom	Instrument Panel Console & Equipment Rack	Nacelle & Pylon	Engine & Gear Box	Empennage, & Fin Tip
f_1	NMxFM	NMxFM	NMxFM	NMxFM	NMxFM	NMxFM
f_2	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM
f_3		NTxFT		FE	FE	NTxFT
f_4		2xNTxFT		FG	FG	2xNTxFT

(1) NOTE: *FM, FT, FE, FG, NM and NT are defined in Paragraph 8.8.1.*

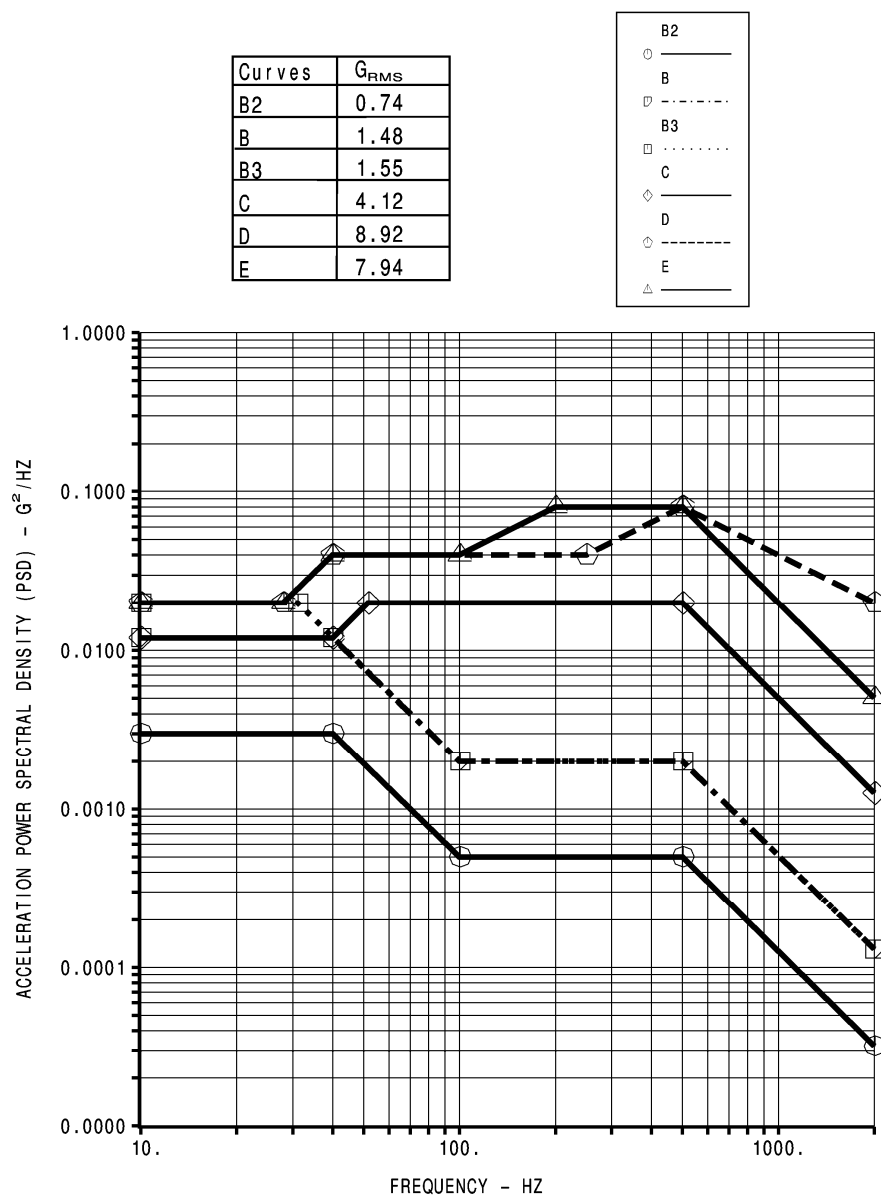
Table 8-2b Sine-on-Random Vibration Test Levels for Helicopters

HELICOPTER VIBRATION TEST CURVE TEST LEVELS (PERFORMANCE)				
Test ⁽¹⁾ Frequency Range, Hz	Sinusoidal Test Levels, An, (g-PK) ⁽²⁾			
	G	H	I	J
$3 < f_n < 10$	$0.04 \times f_n$	$0.05 \times f_n$	$0.08 \times f_n$	$0.17 \times f_n$
$10 < f_n < 20$	$0.04 \times f_n$	$0.05 \times f_n$	$0.08 \times f_n$	4.2
$20 < f_n < 40$	$0.04 \times f_n$	$0.05 \times f_n$	$0.08 \times f_n$	4.2
$40 < f_n < 200$	1.6	2.5	$0.08 \times f_n$	4.2
$200 < f_n < 2000$			16.7	
PSD	Random curve level (g^2/Hz (Grms))			
W_0	0.01 (2.75)	0.01 (2.75)	0.01 (2.75)	0.01 (2.75)

HELICOPTER VIBRATION TEST CURVE TEST LEVELS (ENDURANCE)				
Test ⁽¹⁾ Frequency Range, Hz	Sinusoidal Test Levels, An, (g-PK) ⁽²⁾			
	G	H	I	J
$3 < f_n < 10$	$0.05 \times f_n$	$0.07 \times f_n$	$0.1 \times f_n$	$0.2 \times f_n$
$10 < f_n < 20$	$(0.2 \times f_n) - 1.5$	$(0.28 \times f_n) - 2.1$	$(0.3 \times f_n) - 2$	$(0.3 \times f_n) - 1$
$20 < f_n < 40$	2.5	3.5	4.00	5.00
$40 < f_n < 200$	2.5	3.5	$(0.1 \times f_n)$	5.00
$200 < f_n < 2000$			20.00	
PSD	Random curve level (g^2/Hz (Grms))			
W_0	0.02 (3.89)	0.02 (3.89)	0.02 (3.89)	0.02 (3.89)

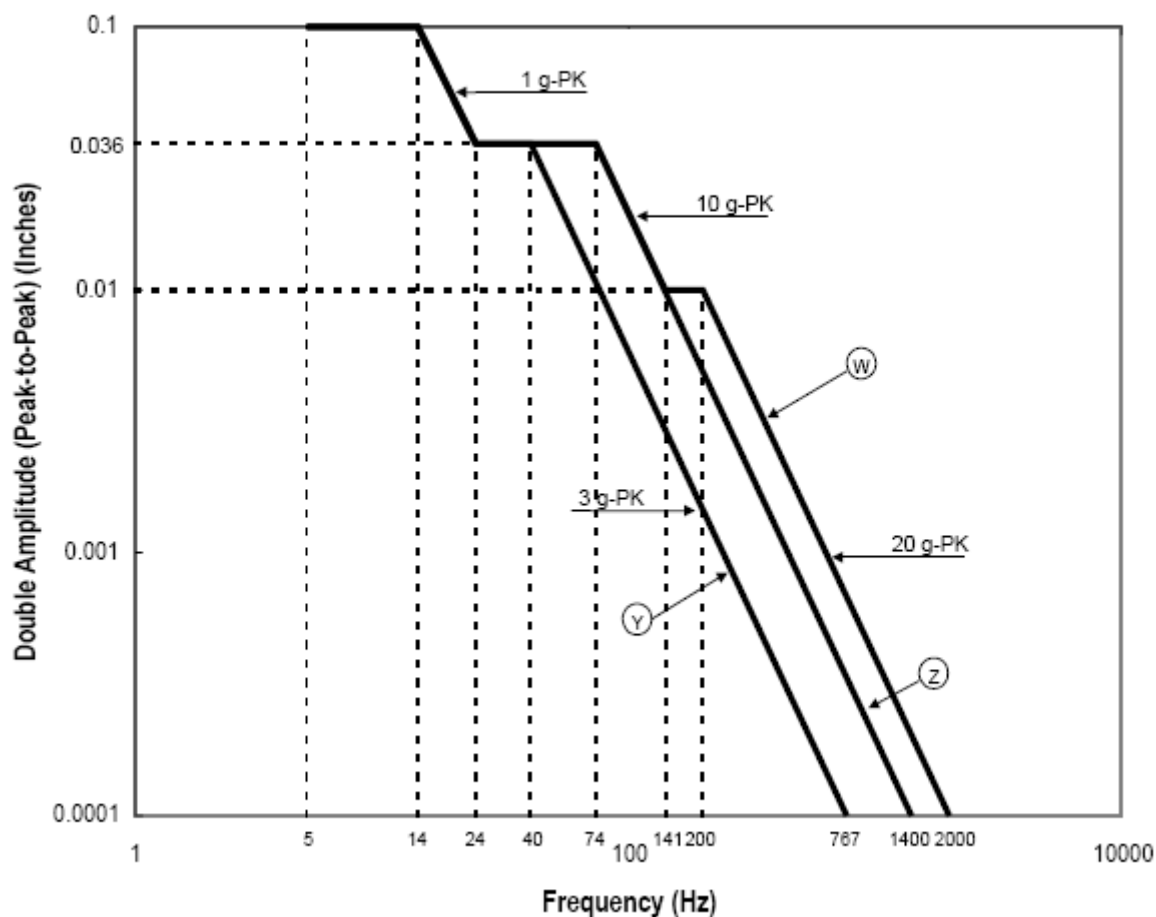
⁽¹⁾ **NOTE 1:** The four sinusoidal frequencies f_1 , f_2 , f_3 and f_4 for each zone are determined in [Table 8.2a](#). The sine on random test curve is shown in [Figure 8-6](#).

⁽²⁾ **NOTE 2:** For equipment located externally on the airframe and exposed to the external airflow, the sinusoidal levels shall be increased by a factor 1.5.



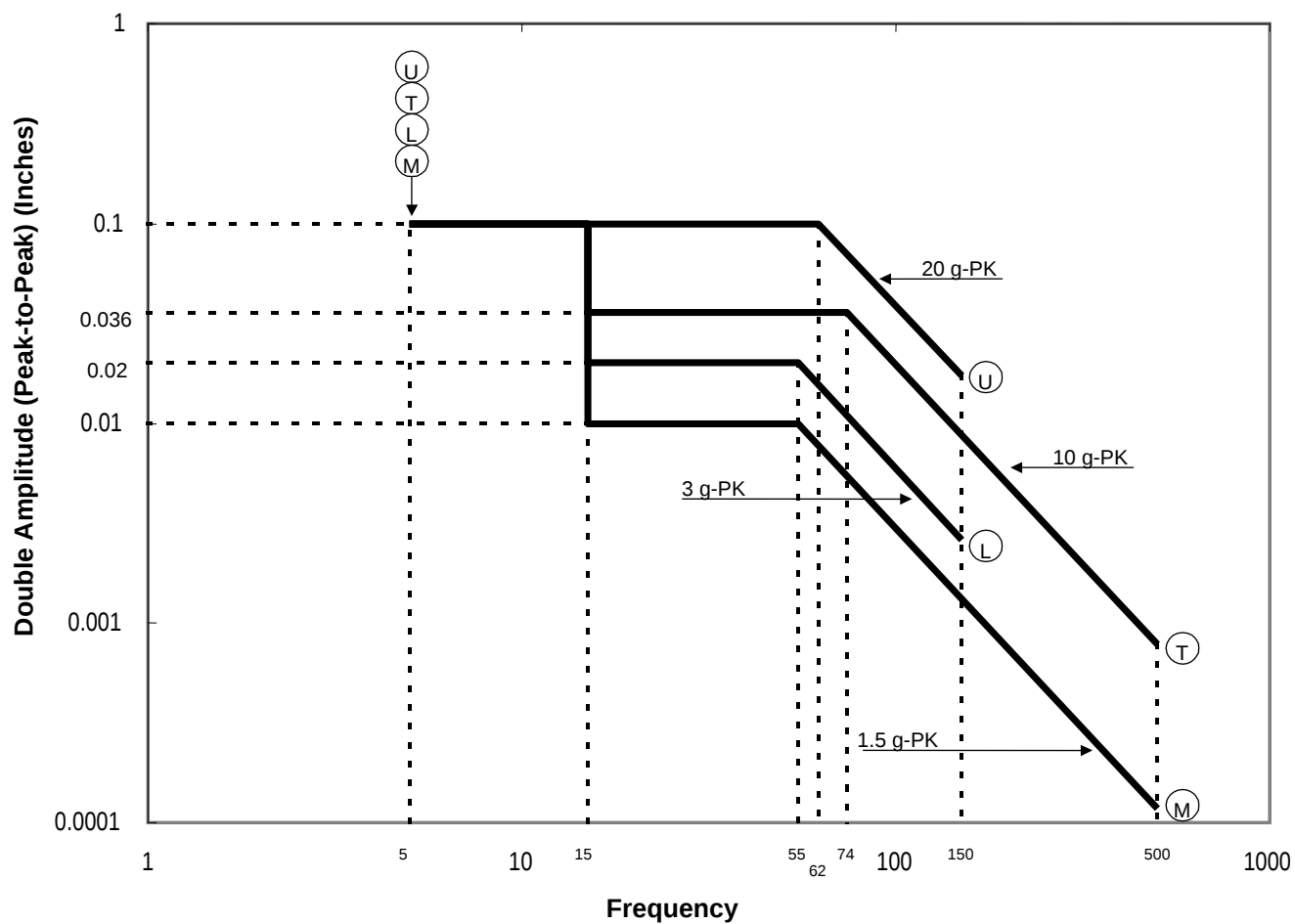
Test Levels at test curve frequency break points										
	10	28	31	40	51.7	100	200	250	500	2000
B2	0.003			0.003		0.0005			0.0005	0.000032
B	0.012			0.012		0.002			0.002	0.00013
B3	0.020		0.020			0.002			0.002	0.00013
C	0.012			0.012	0.020				0.020	0.00126
D	0.020	0.020		0.040				0.040	0.080	0.020
E	0.020	0.020		0.040		0.040	0.080		0.080	0.00505

Figure 8-1 Standard Random Vibration Test Curves for Equipment Installed in Fixed Wing Aircraft with Turbojet or Turbofan Engines



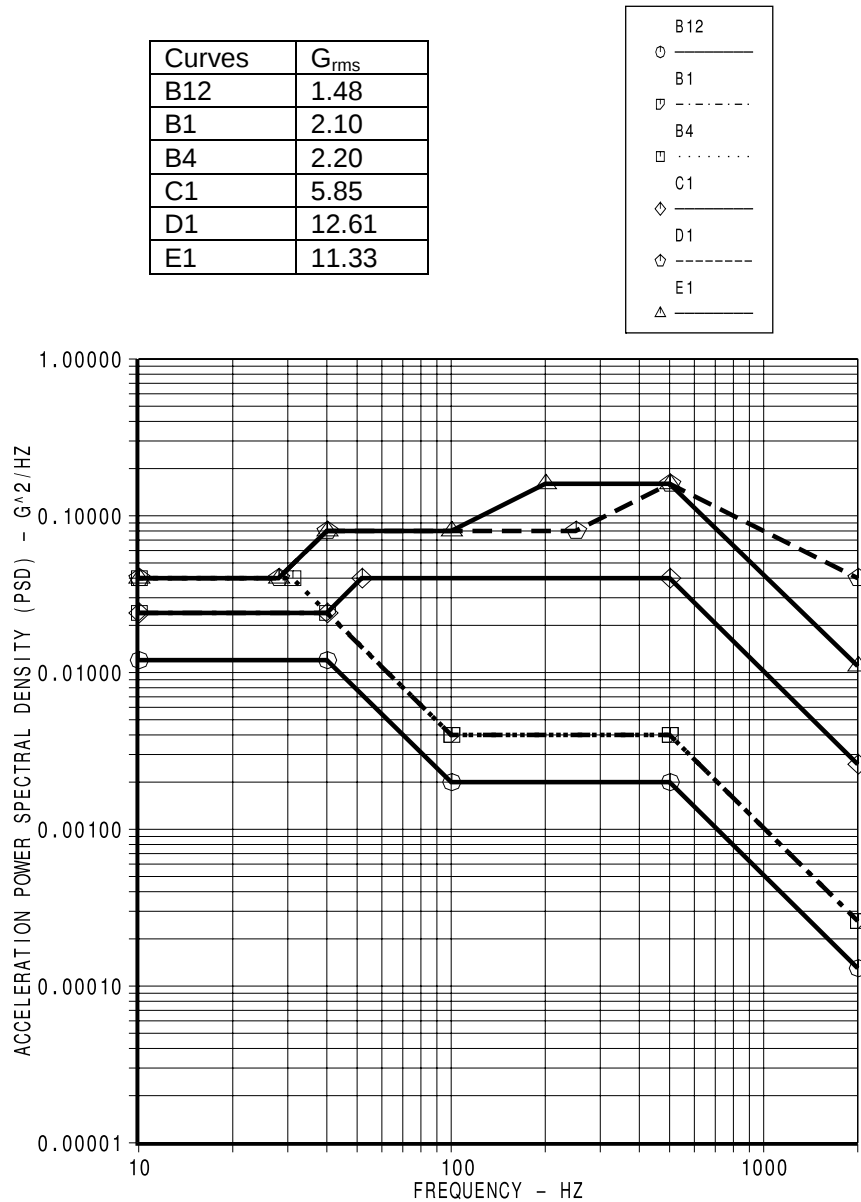
Note: In this figure the use of English units was retained because the graphs were derived from these units originally.

Figure 8-2 Standard and Robust Sinusoidal Vibration Test Curves for Equipment Installed in Applicable Zones in Fixed-Wing Aircraft with Turbojet or Turbofan Engines and Unducted Fan Engines



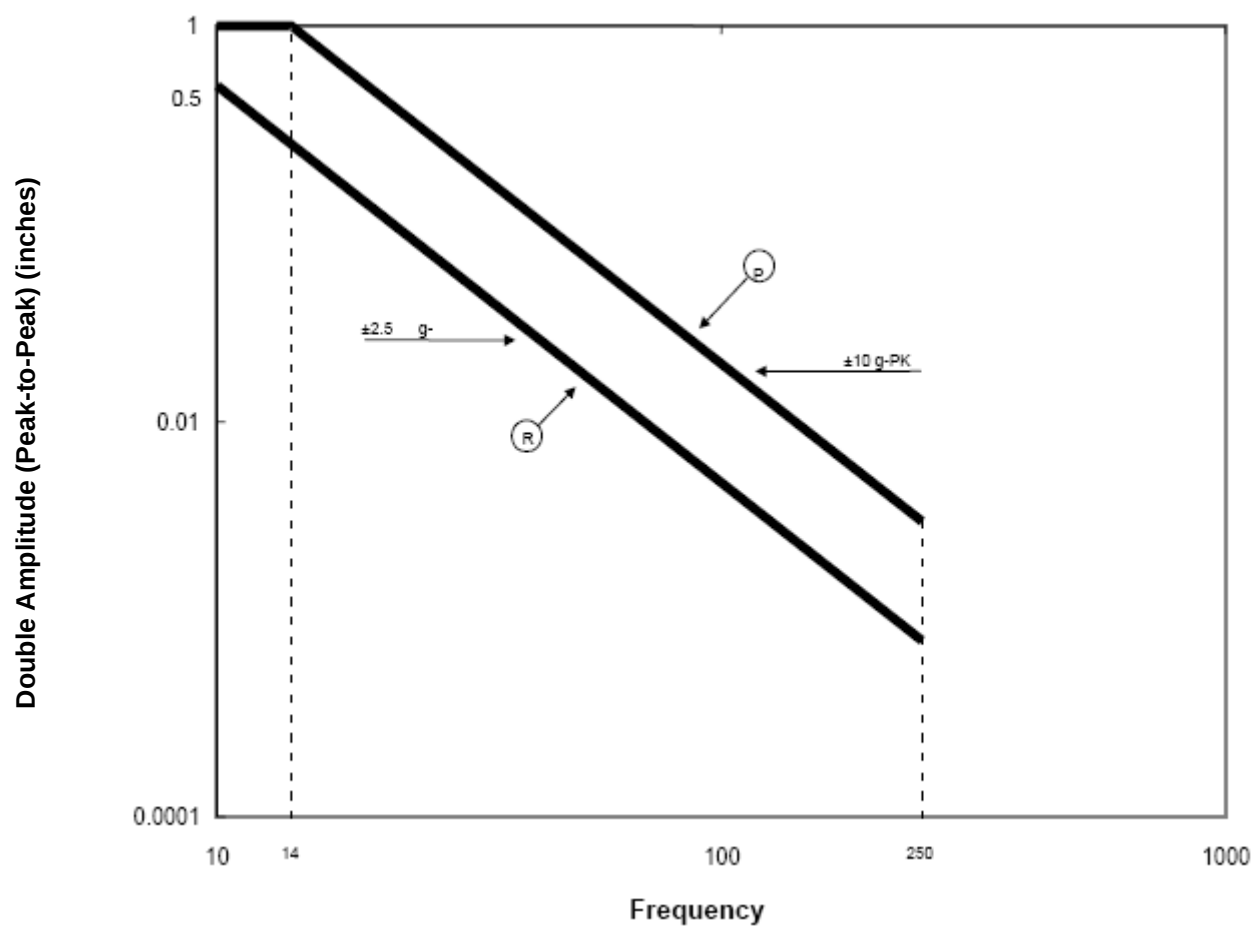
Note: In this figure the use of English units was retained because the graphs were derived from these units originally.

Figure 8-3 Standard Sinusoidal Vibration Test Curves for Equipment Installed in Fixed-Wing Aircraft with Reciprocating or Turbo propeller Engines



Test Levels at test curve frequency break points										
	10	28	31	40	51.7	100	200	250	500	2000
B12	0.012			0.012		0.002			0.002	0.00013
B1	0.024			0.024		0.004			0.004	0.00026
B4	0.040		0.040			0.004			0.004	0.00026
C1	0.024			0.024	0.040				0.040	0.0026
D1	0.040	0.040		0.080				0.080	0.160	0.040
E1	0.040	0.040		0.080		0.080	0.160		0.160	0.011

Figure 8-4 Robust Random Vibration Test Curves for Equipment Installed in Fixed Wing Aircraft with Turbojet or Turbofan Engines



Note: In this figure the use of English units was retained because the graphs were derived from these units originally.

Figure 8-5 High-Level Short Duration Sinusoidal Vibration Test Curves for Equipment Installed on Fixed-Wing Aircraft with Turbojet or Turbofan Engines

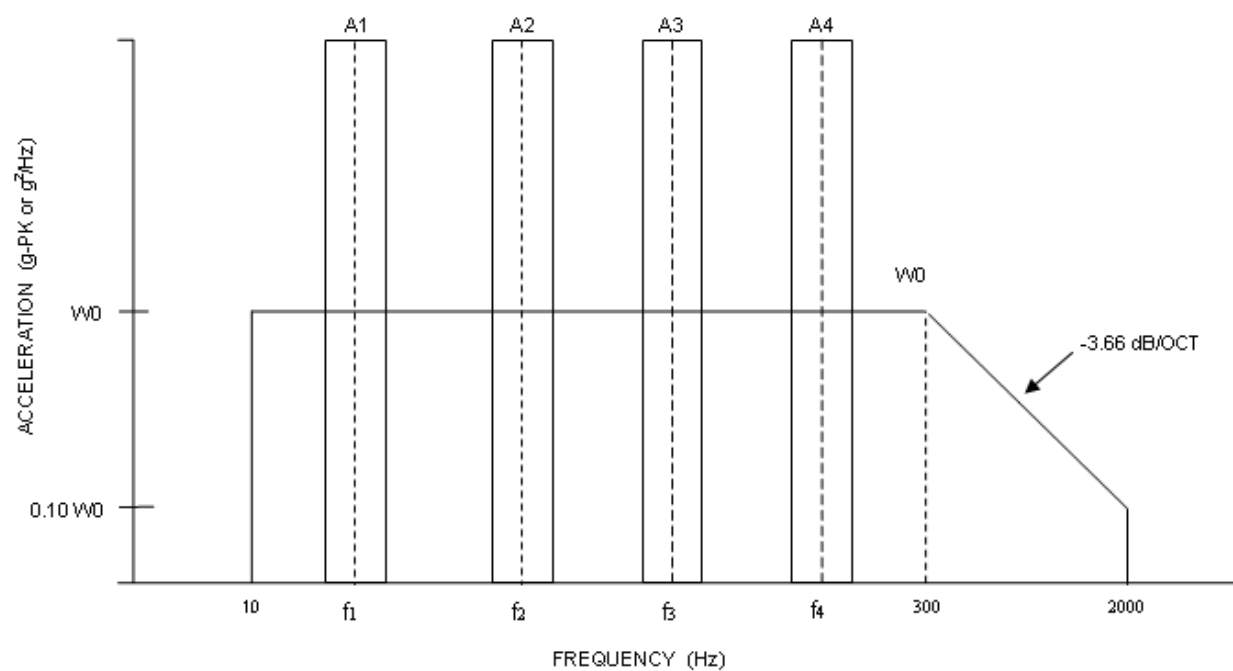


Figure 8-6 Sine-On-Random Vibration Test Curve for Helicopters

Note: W0 is a random PSD curve, g^2/Hz ; A1- A4 are Sinusoidal Curves, g-PK.
 The vibration frequencies are determined using the equations in [Table 8-2a](#). Use these frequencies together with the equations in [Table 8-2b](#) to determine the vibration levels.

TEST	TEST CURVES	W_0	Grms
Performance	F	0.05	3.37
Endurance	F1	0.10	4.76

BREAK POINTS	
FREQUENCY	W/W_0
5	0.126
40	1
200	1
300	0.199

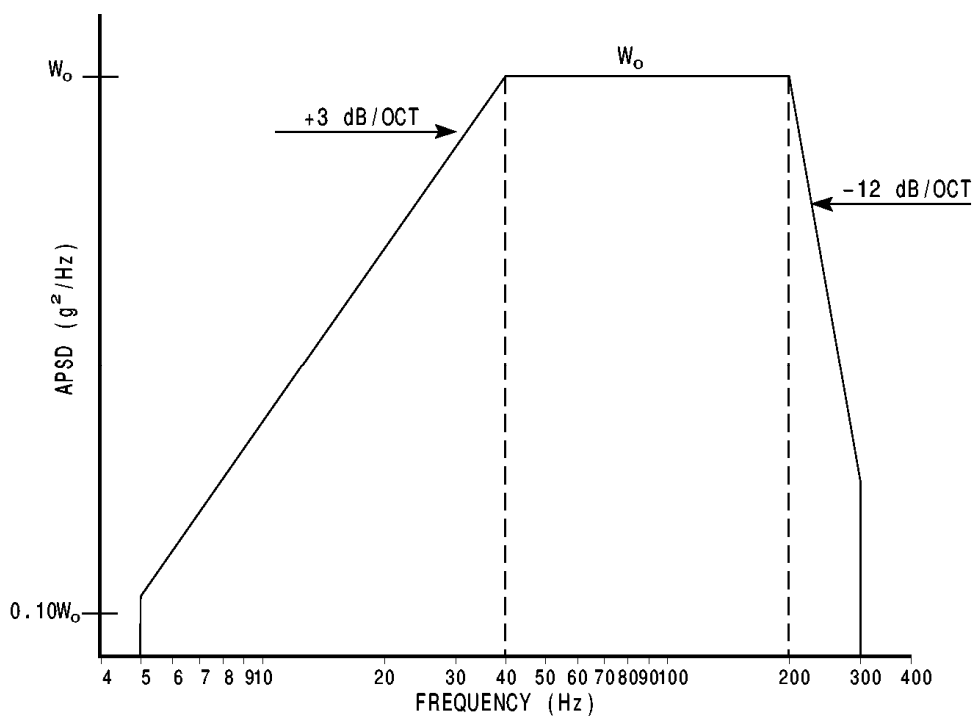


Figure 8-7 Random Test Curves for Helicopters Fuselage, Instrument Panel, and Tail Boom (Unknown Frequencies)

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 9

Explosive Atmosphere

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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9.0 Explosive Atmosphere

9.1 Purpose of the Test

This test specifies requirements and procedures for aircraft equipment that may come into contact with flammable fluids and vapors such as those specified herein. It also refers to normal and fault conditions that could occur in areas that are or may be subjected to flammable fluids and vapors during flight operations.

The flammable test fluids, vapors or gases referred to in this section simulate those normally used in conventional aircraft and that require oxygen for combustion (e.g., monofuels are not included).

These standards do not relate to potentially dangerous environments occurring as a result of leakage from goods carried on the aircraft as baggage or cargo.

Note: The explosive atmosphere tests shall not be conducted prior to any other DO160/ED-14 tests except flammability test (see Subsection 3.2, “Order of Tests”).

9.2 Explosion Proof

Equipment is explosion proof when it has been determined that there is negligible risk that it will cause an explosion of a flammable gas or vapor within the declared environment.

9.3 Equipment Categories

9.3.1 Category A Equipment

Category A equipment is designed so that:

- a. In normal operation the temperature of any surface will not rise to a level capable of causing ignition, nor will any operating part cause ignition so that it meets the non ignition test specified in paragraph 9.6.2.
- b. Ignition of an explosive mixture is contained within the equipment without igniting an explosive atmosphere surrounding it so that it meets the Containment tests specified in paragraph 9.6.1.

Hermetically sealed equipment meeting subparagraph 9.3.1 b. shall be identified as Category A equipment.

9.3.2 Category E Equipment

Category E equipment is not hermetically sealed and not contained in cases designed to prevent flame and explosion propagation.

Such equipment is designed so that in operation the temperature of any internal or external surface will not rise to a level capable of causing ignition, nor will any operating internal part cause ignition so that it meets the non ignition test specified in paragraph 9.6.2.

9.3.3 Category H Equipment

Category H equipment contains hot spot surfaces (external or internal) and are non-spark producing under normal operating conditions (see paragraph 4.6.1).

Such equipment designed so that in normal operation the temperature of any internal or external surfaces will not rise to a level capable of causing ignition so that it meets the components or surface temperature test of paragraph 9.6.3.

Hermitically sealed equipment meeting temperature requirement on external surface shall be identified as Category H equipment.

9.4 General Test Requirements**9.4.1 General**

The test requirements specified below are necessary to assure that the equipment, when tested in accordance with the applicable test procedure, will comply with the standards established in Subsection 9.3.

9.4.2 Test Specimen

The test specimens selected shall be representative of production equipment.

9.4.3 Fuel

Unless otherwise specified, the fuel used may be propane, normal hexane and associated equations.

9.4.4 Fuel Mixtures

- a. For propane, a 1.05 stoichiometric mixture of 3.85% to 4.25% by volume of propane to 96.15% to 95.75% by volume of air. For an example of test apparatus see [Figure 9-1](#).
- b. For hexane, a 1.80 stoichiometric fraction of normal hexane shall be calculated according to the following equations:

(1) Volume (ml) of 95% normal hexane (metric units) =

$$(4.27 \times 10^{-4}) \frac{[\text{net chamber vol (liters)}][\text{chamber pressure (pascals)}]}{[\text{Chamber temp (K)}][\text{Relative density of n-hexane}]}$$

(2) Volume (ml) of 95% normal hexane (English units) =

$$(150.41) \frac{[\text{net chamber vol (ft}^3\text{)}][\text{chamber pressure (psia)}]}{[\text{Chamber temp (R)}][\text{Relative density of n-hexane}]}$$

Note: K = the thermodynamic temperature and is °C + 273.15
 R = the thermodynamic temperature and is °F + 459.67
 The relative density of normal hexane can be determined from Figure 9-2.

The equipment used to vaporize the fuel for use in the explosive atmosphere test should be so designed that a small quantity of air and fuel vapor will be heated together to a temperature such that the fuel vapor will not condense as it is drawn from the vaporizer into the chamber.

When the test facility is designed for fuel vaporization inside the explosion chamber, the fuel may be introduced at the ambient temperature of the test site.

9.5 Equipment Design and Installation Information

Equipment specifications should detail any design constraints applicable to the particular category of equipment enclosure. Such design constraints should include the following as appropriate:

- a. Equipment that may come into contact with flammable fluids or vapors and that in normal operations may produce arcs, sparks or hot surfaces shall be designed, considering its likely manner of installation, to be explosion proof.

- b. Equipment that may come into contact with flammable fluids or vapors, and that under fault conditions may produce arcs, electrical sparks, friction sparks or hot surfaces shall be designed and installed to reduce to an acceptable minimum the overall risk of a fault occurring that will ignite the flammable vapors.
- c. In designing the air supply system for forced air ventilated equipment, the possibility of contamination of the air by flammable vapors shall be taken into account. If the equipment and its ducting, including joints, are in an area that can be so contaminated, they shall be capable of meeting the conditions appropriate to the environment.
- d. The specification for Category A equipment, paragraph 9.3.1, should consider the design requirements of flange and hole dimensions or other equivalent means, such as flame traps, for adequate safety from flame propagation. This information is contained in national documents.

9.6 Test Procedures

9.6.1 Containment Test

9.6.1.1 Preparation for Test

- a. Preparation of Test Case or Enclosure – The purpose of this procedure is to intentionally fill the case or enclosure under test with a volatile gas mixture then ignite it. Drilling and tapping openings in the case or enclosure for inlet/outlet hose connections to the fuel-vapor-air mixture circulation system and for mounting a spark gap device may be required. The case volume shall not be altered by more than ± 5 percent by any modification to facilitate the introduction of explosive vapor.
- b. Hose Installation - When inserting a hose from a blower, adequate precaution shall be taken to prevent ignition of the ambient mixture by backfire or the release of pressure through the supply hose.
- c. Spark Gap Device - A spark gap device for igniting the explosive mixture within the case or enclosure shall be provided. The case or enclosure may be drilled and tapped for the spark gap device, or the spark gap device may be mounted internally.
- d. Case Installation - The case or enclosure with either the test item or a model of the test item of the same volume and configuration in position within the case or enclosure shall be connected and oriented in the explosion chamber mechanically and electrically, as recommended by the manufacturer for normal service installation. This shall include any cooling provisions, as necessary to perform the tests described herein.
- e. Test Facility – The required apparatus consists of a chamber or cabinet together with auxiliary instrumentation capable of establishing, maintaining and monitoring the specified test conditions. Use a chamber with a means of igniting the fuel-air mixture such as a spark-gap device, as well as a means of determining the explosiveness of a sample of the mixture such as a thermocouple or pressure transducer. An alternative method of determining the explosive characteristics of the vapor is by using a

calibrated explosive gas meter which verifies the degree of explosiveness and the concentration of the fuel-air mixture.

9.6.1.2 Performance of Test

The following test sequence shall be performed three times as follows:

Step 1: The chamber shall be sealed and the internal pressure maintained at site level pressure. The ambient chamber temperature shall be at least 25°C. An explosive mixture within the chamber shall be obtained by using the mixture defined in paragraphs 9.4.3 and 9.4.4. Circulate (by blower or pump) fuel/air mixture through test unit to insure explosive mixture within test unit.

Step 2: The internal case ignition source shall be energized in order to cause an explosion within the case. The occurrence of an explosion within the case may be detected by use of a thermocouple inserted in the case and connected to an appropriate temperature recorder outside the test chamber. If ignition of the mixture does not occur immediately, the test shall be considered void and shall be repeated with a new explosive charge.

Step 3: At least five internal case explosions shall be performed. If the case tested is small (not in excess of 1/50 of the test chamber volume) and if the reaction within the case upon ignition is of an explosive nature without continued burning of the mixture as it circulates into the case, more than one internal case explosion, but not more than five, may be produced without recharging the entire chamber. If the case volume is greater than 1/50 of the test chamber volume an alternative to purging the chamber after each case explosion would be to verify the explosiveness of the mixture after each case explosion. Ample time shall be allowed between internal case explosions for replacement of burnt gases with fresh explosive mixture within the case. If the internal case explosions produced did not cause a main chamber explosion, the explosiveness of the fuel-air mixture in the main chamber shall be verified by igniting a sample of the mixture with a spark plug or glow plug. If the air-vapor mixture in the main chamber is found not to be explosive, the test shall be considered void and the entire procedure repeated.

9.6.1.3 Failure Criteria

If the internal case explosion causes a main chamber explosion, the test item shall have failed the test and no further tests need be conducted.

9.6.2 Non ignition Test

9.6.2.1 Preparation for Test

- a. The test item shall be connected and oriented mechanically and electrically as recommended by the manufacturer for normal service installation. This shall include any cooling provisions as necessary to perform the tests described herein so that

normal electrical operation is possible and mechanical controls may be operated through the pressure seals from outside the chamber. External covers of the test item shall be removed or loosened to facilitate the penetration of the explosive mixture. Large test items may be tested one or more units at a time by extending electrical connections through the cable port to the balance of the associated equipment located externally.

- b. The test item shall be operated to determine that it is functioning properly.
- c. Mechanical loads on drive assemblies and servomechanical and electrical loads on switches and relays may be simulated if proper precaution is given to duplicating the normal load in respect to torque, voltage, current, inductive reactance, etc. In all instances, it is preferable to operate the test item as it normally functions in the installed environment.

9.6.2.2 Performance of Test

The test shall be conducted at site level pressure.

Step 1: The test chamber shall be sealed and the ambient temperature within shall be raised to the Operating High Temperature, given in Table 4-1, for which the equipment is designed to operate. The temperature of the test chamber and the chamber walls shall be permitted to rise to within 11°C of the chamber ambient air, prior to the introduction of the explosive mixture, to prevent condensation of the explosive medium.

Step 2: The required quantity of fuel (paragraph 9.4.4) shall be introduced into the chamber. Circulate the test atmosphere for at least three minutes to allow for complete vaporization of fuel and the development of a homogenous mixture.

Step 3: At this time all electrical contacts of the test item shall be actuated. The operation of the test item shall be continuous throughout this period and all making and breaking of electrical contacts shall be conducted as frequently as deemed practicable.

Step 4: If no explosion has occurred as a result of the test item operation, the potential explosiveness of the air-vapor mixture shall be verified by igniting a sample of the mixture with a spark gap or glow plug. If the air-vapor mixture is not found to be explosive, the test shall be considered void and the entire procedure repeated.

9.6.2.3 Failure Criteria

If the item causes an explosion, it shall have failed the test and further tests need not be conducted.

9.6.3 Components or Surface Temperature Test

9.6.3.1 Preparation for Test

The test item shall be placed in the test chamber in accordance with subparagraph 9.6.2.1. the suspected components or surfaces to be tested for thermal ignition shall be instrumented with thermocouples operating in a range of 65 to 260°C.

9.6.3.2 Performance of Test

The test shall be conducted as follows:

Step 1: The test chamber shall be sealed and the ambient temperature within shall be raised to the Operating High Temperature, given in Table 4-1, for which the equipment is designed to operate.

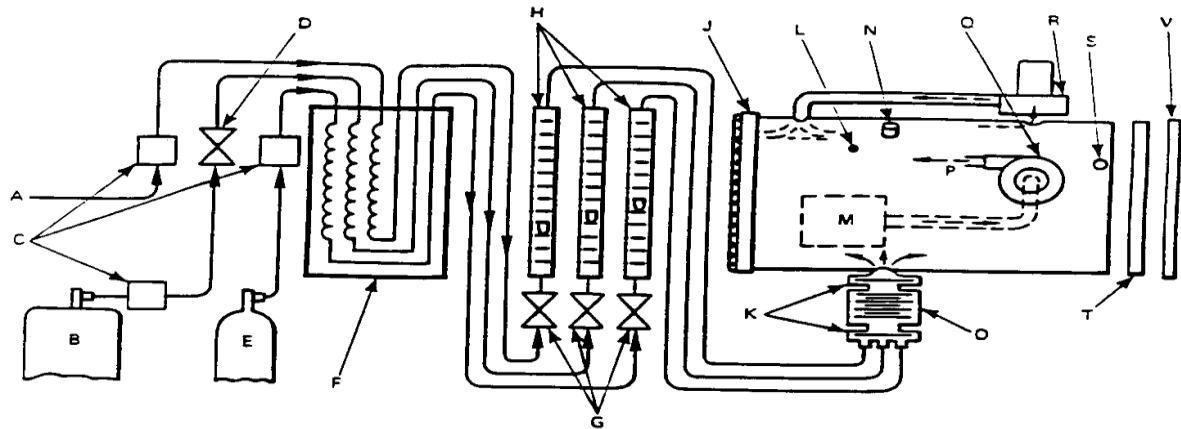
Step 2: After the equipment stabilizes the equipment shall be turned on and operated in its normal mode until thermal stabilization of the equipment has been attained. The maximum temperatures attained at the suspected components or surfaces shall be recorded continuously from the initial powering of the equipment to its stabilization. If a temperature in excess of 204°C is attained, the test shall be terminated.

9.6.3.3 Failure Criteria

In Step 2 above, if the item exceeds 204°C, the test item shall have failed the test and further tests need not be conducted

Table 9-1 Equipment Categories and Test Requirements

Equipment Categories	Requirements and Tests
A (hermetically sealed)	Containment test 9.6.1 or hermitically sealed case. Surface temperature test 9.6.3.
E	Non ignition test of 9.6.2.
H	Surface temperature test 9.6.3 (non spark producing equipment or hermitically sealed)



Legend

A	AIR	K	DIAPHRAGM CHECK VALVES
B	PROPANE GAS CONTAINER	L	CYLINDRICAL EXPLOSION CHAMBER
C	REDUCING VALVES	M	UNIT UNDER TEST
D	GAS CUT-OFF VALVE OPERATED BY MICRO-SWITCHES ON EXPLOSION CHAMBER	N	VENT
E	OXYGEN BOTTLE	O	MIXING CHAMBER
F	HEAT EXCHANGER TO BRING THE GASES TO STANDARD TEMPERATURE	P	WASTE TO ATMOSPHERE
G	NEEDLE VALVES	Q	EXTRACTOR FOR CHARGING UNIT UNDER TEST
J	BOTH ENDS COVERED BY DIAPHRAGMS (E G PAPER, POLYETHYLENE) HELD ON BY RUBBER BANDS	R	STIRRING BLOWER
		S	MICRO-SWITCH (ONE T EACH END) RELEASED WHEN H FLOW METERS RUBBER BAND IS DISPLACED BY EXPLOSION
		T	DIAPHRAGM
		V	RUBBER BAND

Figure 9-1 Example of Apparatus for Testing in Explosive Atmospheres

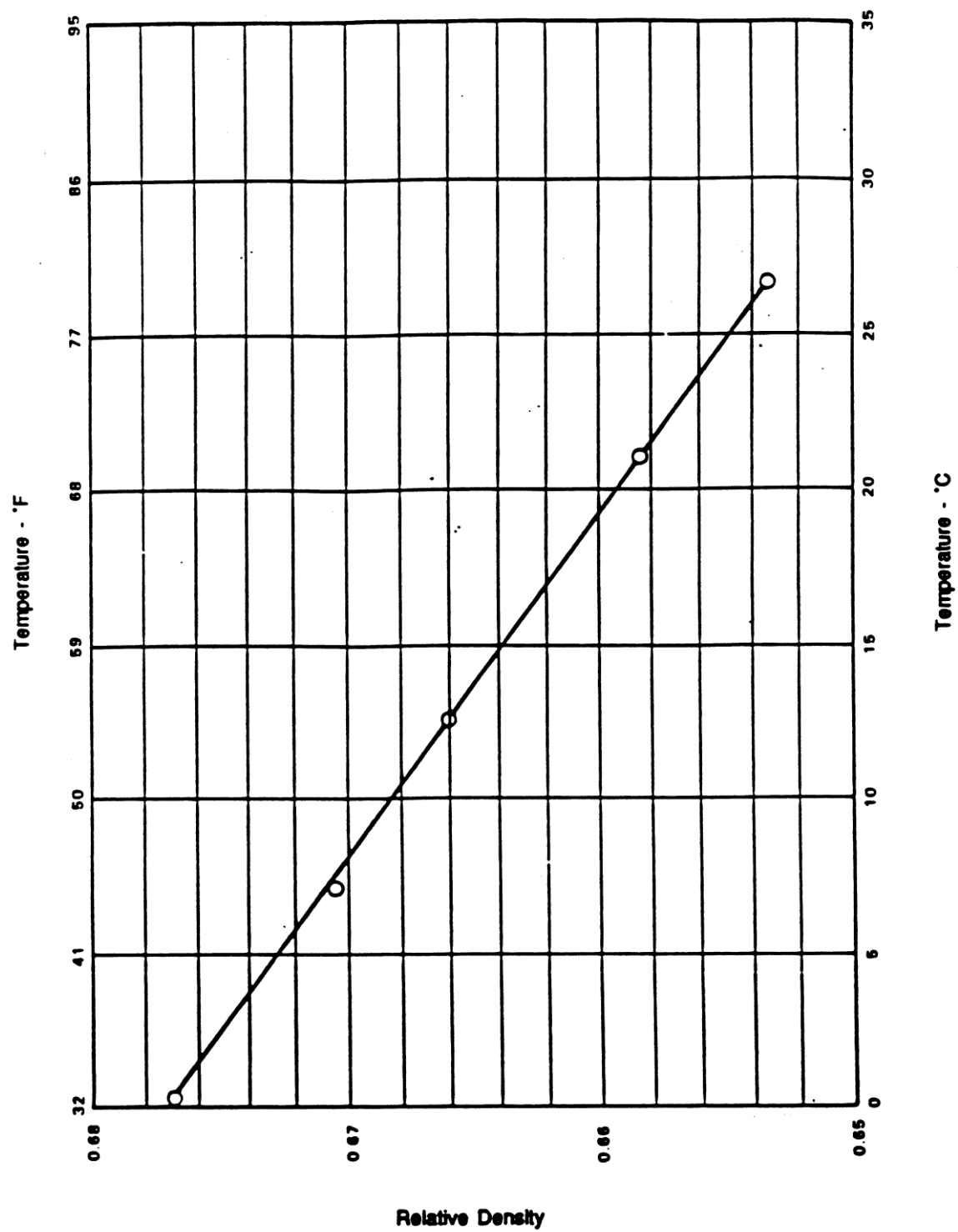


FIGURE 9-2 RELATIVE DENSITY OF N-HEXANE

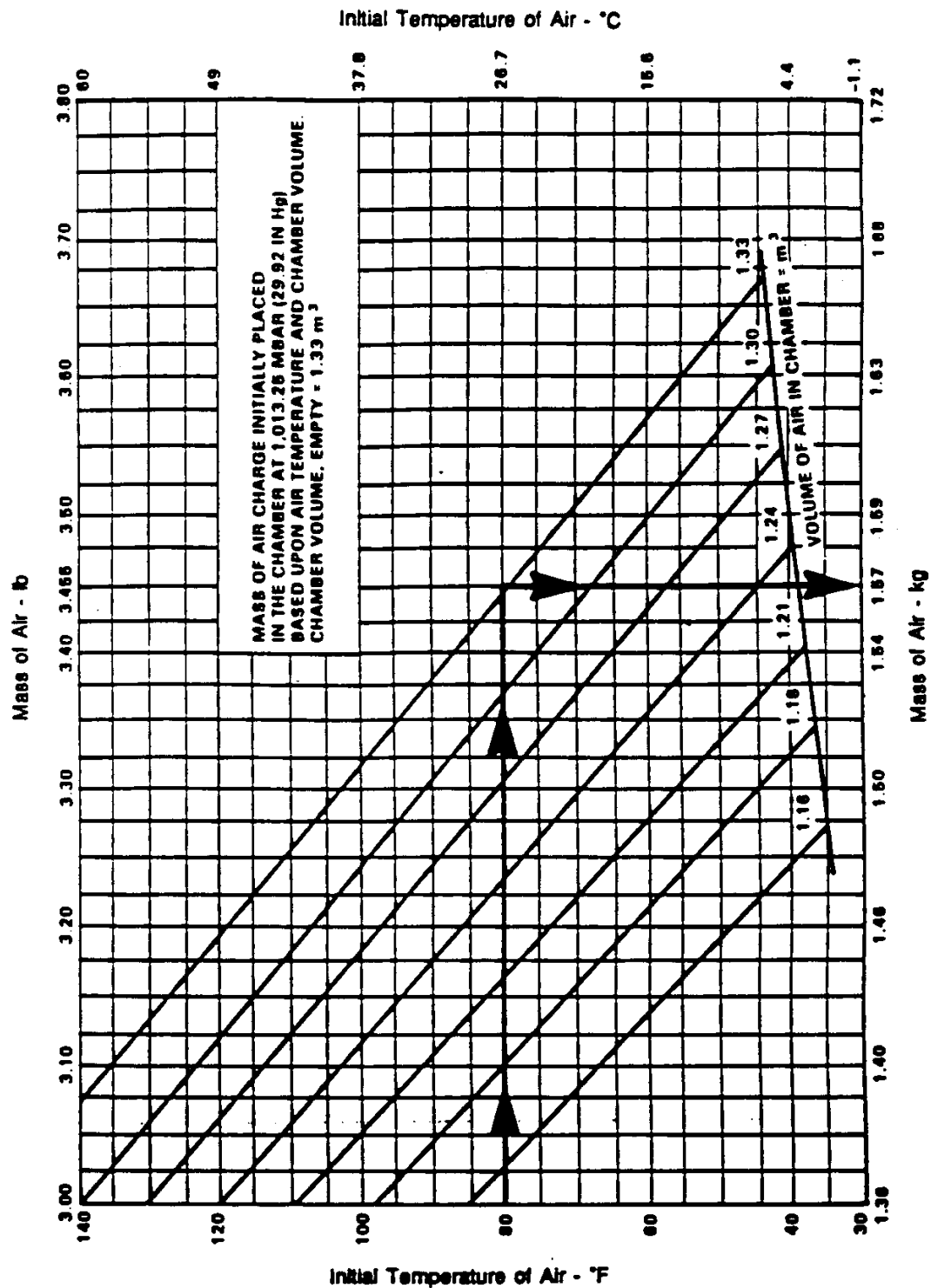


Figure 9-3 Mass of Air Charge vs Temperature

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

User's Guide Appendix 9

Explosive Atmosphere

**Based on
DO-160G Section 9.**

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User's Guide, Appendix 9

Section 9 defines the environment, test procedures and requirements. In order to properly interpret the procedures and requirements outlined in Section 9, a User's Guide is provided in Appendix 9.

The User's Guide includes rationale, guidance and background information for the environment, test procedures and requirements, guidance in applying the requirements, and lessons learned from aircraft and laboratory experience. This information should help user's understand the intent behind the requirements, should aid in tailoring requirements as necessary for particular applications and should help user's develop detailed test procedures based on the general test procedures in Section 9.

The User's Guide follows a parallel format to the main body of Section 9 for easy cross reference. Paragraph numbers corresponding to each paragraph in Section 9 are included the User's Guide. Where there is no additional information provided in the User's Guide, the paragraph header is provided but the following paragraph is left blank.

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9.A.0 Explosive Atmosphere**9.A.1 Purpose of the Test**

This section of DO-160 is intended to provide test procedures and test levels that can be used to test equipment for explosive atmosphere. It is the responsibility of the installer to make sure the test results satisfy the certification requirements of the proposed installation. This user's guide does not contain requirements; it is intended to provide background information and considerations that improve the likelihood of successful test results.

9.A.2 Explosion Proof**9.A.3 Equipment Categories****9.A.3.1 Category A Equipment****9.A.3.2 Category E Equipment****9.A.3.3 Category H Equipment****9.A.4 General Test Requirements****9.A.4.1 General****9.A.4.2 Test Specimen****9.A.4.3 Fuel****9.A.4.4 Fuel Mixture****9.A.5 Equipment Design and Installation Information****Aircraft Zone Definitions and Equipment Requirements**

Equipment should be installed in aircraft zones depending on their ability to prevent vapor explosion during their normal functioning and depending on probability that exist in considered zone, during abnormal functioning in failure mode. Definition of Zone provided below.

Aircraft Zone 1

Aircraft Zone 1 is an aircraft area in which uncovered flammable fluids or vapors exist, or can exist, either continuously or intermittently (e.g., in fuel tanks or within fuel or hydraulic systems). Equipment installed in such environment should not be able to ignite the surrounding atmosphere in their normal or double failure conditions of operation.

Aircraft Zone II

Aircraft Zone II is an aircraft area in which flammable mixtures can be expected to occur only as a result of a single fault-causing spillage or leakage. Equipment installed in such Environment should not be able to ignite the surrounding atmosphere in their normal or faulty possible operation modes. Only equipment single failure should be considered.

Aircraft Zone III

Aircraft Zone III is an aircraft area in which flammable mixtures cannot be expected to occur as a result of a single fault-causing spillage or leakage. Equipment installed in such Environment should not be able to ignite the surrounding atmosphere in their normal operation modes.

Aircraft Zone IV

Aircraft Zone IV is a designated fire zone or an aircraft area in which flammable mixtures cannot be expected to occur as a result of a double fault-causing spillage or leakage. No requirement applies to equipment located in such zone.

9.A.6 Test Procedures

9.A.6.1 Containment Test

9.A.6.1.1 Preparation for Test

9.A.6.1.2 Performance of Test

9.A.6.1.3 Failure Criteria

9.A.6.2 Non Ignition Test

9.A.6.2.1 Preparation of Test

9.A.6.2.2 Performance of Test

9.A.6.2.3 Failure Criteria

9.A.6.3 Components of Surface Temperature Test

9.A.6.3.1 Preparation for Test

9.A.6.3.2 Performance of Test

9.A.6.3.3 Failure Criteria

If faulty modes are to be tested, the equipment should be turned on and operated in its possible faulty modes until thermal stabilization of the equipment has been attained. The temperatures attained at the suspected components or surfaces should be recorded continuously from the initial powering of the equipment to its stabilization. If a temperature in excess of 204°C is attained at any time during the period, the test should be terminated.

Table 9-A-1 Equipment Categories and Test Requirements

Figure 9-A-1 Example of Apparatus for Testing in Explosive Atmospheres

Figure 9-A-2 Relative Density of N-Hexane

Figure 9-A-3 Mass of Air Charge vs. Temperature

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 10

Waterproofness

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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10.0 Waterproofness**10.1 Purpose of the Test**

These tests determine whether the equipment can withstand the effects of liquid water being sprayed or falling on the equipment or the effects of condensation.

These tests are not intended to verify performance of hermetically sealed equipment. Therefore, hermetically sealed equipment may be considered to have met all waterproofness requirements without further testing. Equipment shall be considered hermetically sealed when the seal is permanent and airtight.

10.2 Equipment CategoriesCategory Y

Equipment that is installed in locations where it is subjected to condensing water in the course of normal aircraft operations is identified as Category Y. For equipment intended for installation in such locations, the condensing water proof test procedure applies and the equipment is identified as Category Y.

Category W

Equipment that is installed in locations where it is subjected to falling water (generally the result of condensation) in the course of normal aircraft operations is identified as Category W. For equipment intended for installation in such locations, the drip proof test procedure applies and the equipment is identified as Category W.

Category R

Equipment installed in locations where it may be subjected to a driving rain or where water may be sprayed on it from any angle is identified as Category R. For equipment intended for installation in such locations, the spray proof test procedure applies. Equipment that has passed the Category R requirements may be considered to meet the Category W requirement without further testing.

Category S

Equipment installed in locations where it may be subjected to the forces of a heavy stream of fluid such as would be encountered in aircraft de-icing, washing or cleaning operations is identified as Category S. For equipment intended for installation in such locations the continuous stream proof procedure applies. Water is used in this test to simulate the actual fluid forces. Equipment that has passed the Category S requirements may be considered to meet the Category W requirements without further testing.

10.3 Test Procedures**10.3.1 Condensing Water Proof Test**

Two temperature chambers will be used for this test. Chamber 1 will be set to -10°C, while chamber 2 will be set to 40°C and 85% RH. Mount the equipment under test according to the manufacturer's specifications with all connectors and fittings engaged into chamber 1. With the equipment not operating let the equipment stabilize for a minimum of three hours. Chamber 2 shall be stabilized at 40°C and 85% humidity during this same time. After the three-hour stabilization, transfer the equipment to chamber two within a five minute transition time. Mount the equipment according to the manufacturer's specifications with all connectors and fittings, including ventilation, engaged into chamber 2 within a maximum delay of 5 minutes. Turn the equipment on and let it operate for 10 minutes (+1 minute, - 0 minutes). Following the 10 minute operating period DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

10.3.2 Drip Proof Test.

Prior to the start of the Drip Proof test, with the equipment under test not operating, stabilize the equipment to a temperature of at least 10 degrees Celsius above the temperature of the water to be used for the drip test. Place equipment according to the manufacturer's specifications with all connectors and fittings engaged. With the equipment not operating, subject it to water falling at a uniform rate from a minimum height of one meter above the top surface of the equipment under test for a minimum of 15 minutes. The test equipment shall emit a volume of water greater than 140 l/m²/hr dripping from a dispenser with 0.33 mm nominal diameter drip holes on a 25 mm pattern as shown in Figure 10-1. Note: To meet the 140l/m²/hr or greater volume of water. A pre-calibration and post calibration of the volume of water emitted from the drip table shall be conducted and the level in the drip table shall be noted. The drip hole pattern shall be sufficiently large to meet or exceed the horizontal cross sectional area of the equipment under test when installed in its normal position. At the conclusion of the test DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

10.3.3 Spray Proof Test

Mount the equipment according to the manufacturer's specification with all connectors and fittings engaged. With the equipment operating, subject it to a shower of water from a shower head nozzle as depicted in Figure 10-2. The water shall be directed perpendicular to the most vulnerable area(s) of the equipment as stated in the applicable equipment performance standards.

Each of the areas under test shall be subjected to the spray for a minimum of 15 minutes. If desired, the test may be applied simultaneously to more than one area at a time by using an appropriate number of showerheads. The showerhead shall be located not more than 2.5 m from the area under test and shall emit a volume of water greater than 450 liters per hour. At

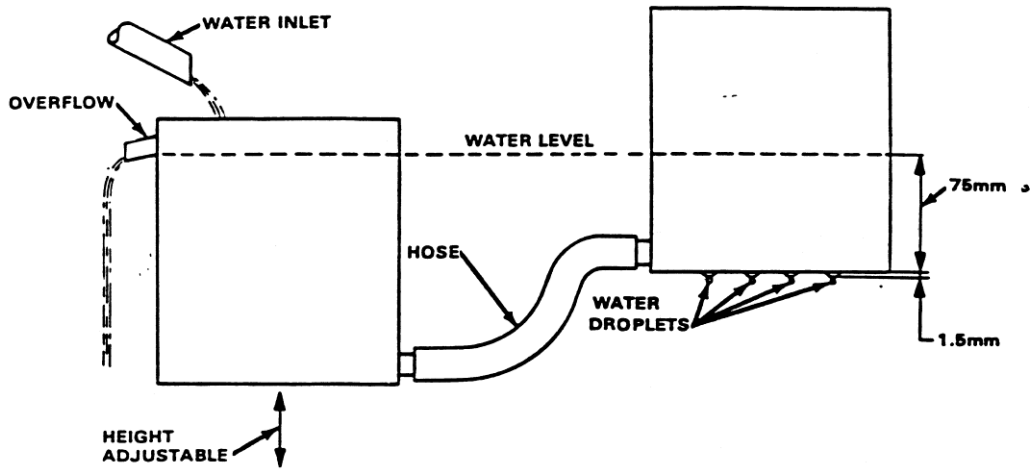
the conclusion of the test DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

10.3.4 Continuous Stream Proof Test

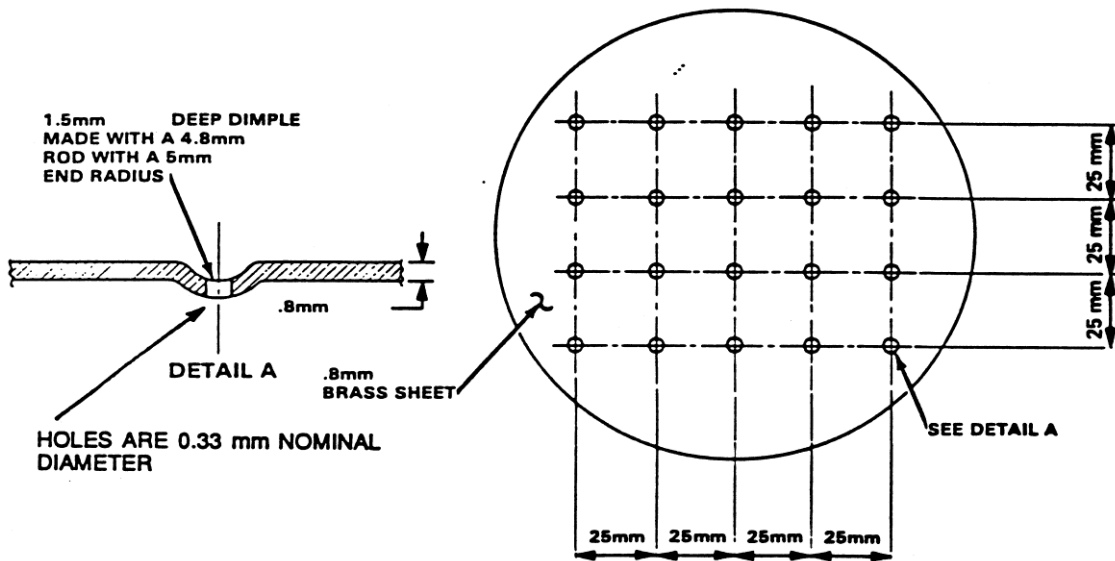
This test is used to supplement the fluids susceptibility test in Section 11.0. Susceptible materials such as gaskets shall be subjected to the appropriate tests of Section 11.0 prior to the performance of this test. This test shall be performed with water at a temperature of 50 degrees C.

Mount the equipment according to the manufacturer's installation instructions in a manner that simulates the aircraft installation. Connectors or other fittings shall be connected as in normal operation. The equipment need not be operated during this test.

Subject the equipment, particularly in areas where parts are mated with a resilient gasket, to a continuous stream of water on all sides for a minimum five minutes on each side. The stream of water shall be of sufficient pressure to produce, through a 6.4-mm diameter nozzle, at least a six-meter vertical stream of water. The equipment shall be subjected to this stream of water from a distance of one to two meters. At the conclusion of the test DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.



(A) TEST SETUP FOR WATER PROOFNESS TEST



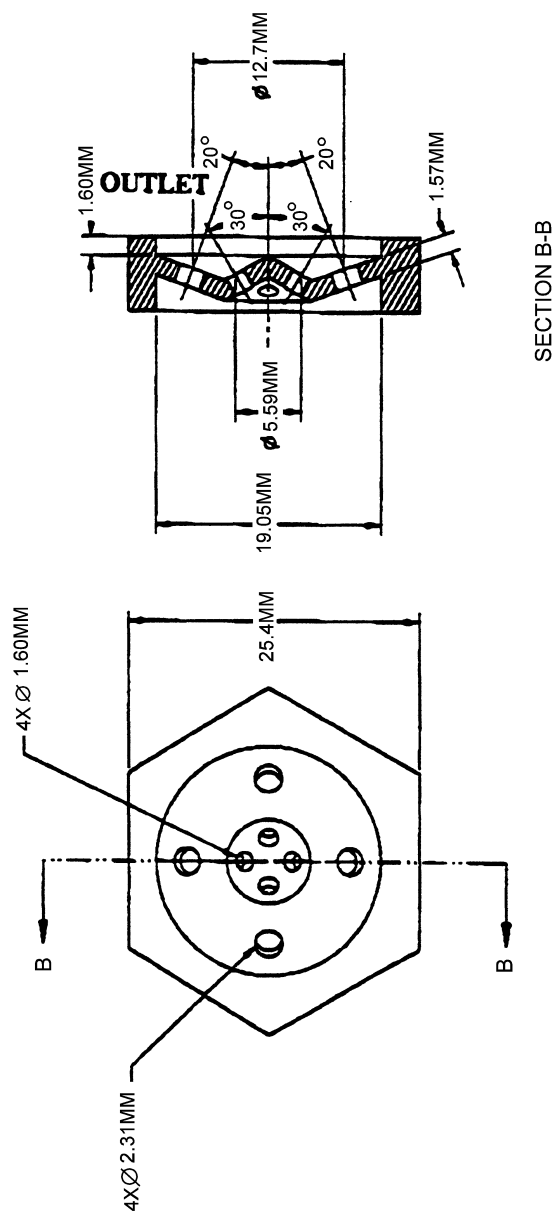
(B) DISPENSER DETAILS

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NOTE: Container size and number of holes as required to meet the flow rate requirement of paragraph 10.3.1.

FIGURE 10-1 DRIP PROOF TEST DETAILS

Note: To meet the $140\text{l/m}^2/\text{hr}$ or greater volume of water. A pre-calibration and post calibration of the volume of water emitted from the drip table shall be conducted and the level in the drip table shall be noted.

**FIGURE 10-2 SHOWER HEAD DETAILS**

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 11

Fluids Susceptibility

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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11.0 Fluids Susceptibility

11.1 Purpose of the Test

These tests determine whether the materials used in the construction of the equipment can withstand the deleterious effects of fluid contaminants. Fluids susceptibility tests should only be performed when the equipment will be installed in areas where fluid contamination could be commonly encountered. The fluids are representative of those commonly used fluids encountered in airborne and ground operations. Fluids not listed herein and for which susceptibility tests are indicated shall be included in the relevant equipment specification.

11.2 Precautions

Since many contaminants may have flash points within the test temperature range, care should be taken to ensure that adequate safety measures are taken to limit the possibility of fire or explosion.

Some contaminants may themselves or in combination with other contaminants or with the test sample be toxic. Due consideration should be given to this possibility before commencing the tests.

11.3 Equipment Categories

Category F

Equipment that has passed the tests covered in this section is identified as Category F. Details of the test fluids involved and the methods used shall be provided in the Environmental Qualification Form (See Appendix A).

Note: Sections 10.0 and 14.0 of this document cover waterproofness and salt spray tests, respectively. Section 11.0 covers seven general classes of other contaminating fluids. In addition there are 25 specific fluids that are used to test these classes. Table 11-1 contains the class of fluids, the specific fluids and the temperatures required in these tests. Testing of all 25 fluids or all 7 general classes of contaminated fluids is not required to claim category F. It is required to specify fluids used, test method and temperature of exposure in the test procedure and the Environmental Qualification Form.

11.4 Test Procedures

11.4.1 Spray Test

Connect the equipment mechanically and electrically as defined in the relevant equipment specification. The equipment is not required to operate during this test and shall be at room ambient.

- (a) Spray the specified fluid(s) to the entire surface of the test item that is likely to be exposed. The spray shall be a fine mist maintained at the temperatures in Table 11-1 and shall be directed toward every major surface, seal and connector of the equipment sample under test. Maintain surfaces in a wetted condition for 8 hours followed by a drying period of 16 hours at 65°C. If it is difficult to maintain a wetted condition and the equipment specification requires the spray test rather than the immersion test, it shall be acceptable to thoroughly spray the equipment at intervals of four hours maximum, and allow it to stabilize at standard ambient temperature.
- (b) Visually examine the test item for degradation of materials, protective finishes, and physical changes. Repeat Step (a) until three 24-hour cycles have been completed. At the end of the third spray period, while still wet, the product shall be operated for 10 minutes minimum. After the last cycle, ramp the chamber to standard ambient temperature (avoiding temperature shock) and operate the unit until stabilized or for a minimum of 30 minutes. DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.
- (c) Repeat steps (a) and (b) for additional fluids.
- (d) After the completion of testing all of the fluids. DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: If the equipment is to be tested with more than one class of contaminating fluid, it should normally be tested with each fluid separately. However, simultaneous testing is permitted if fluids are of the same base (Example: oil base should not be followed by water base fluid). Fluids should not be pre-mixed prior to spraying, and the order of application should be as specified in the equipment specification. Unless otherwise noted in the equipment specification, the total exposure time for simultaneous application of fluids should be the same as the exposure time for a single fluid. The precautions noted elsewhere in this section should be observed.

At the completion of the test, the equipment shall be inspected and shall show no evidence of damage of any internal or external component.

11.4.2 Immersion Test

Connect the equipment mechanically and electrically as defined in the relevant equipment specification. The equipment is not required to operate during this test and shall be at ambient temperature. Do not pre-mix any solution.

Immerse the equipment in the appropriate fluid for a minimum of 24 hours. The fluid temperature shall be maintained at the temperature shown in Table 11-1 and shall cover the test specimen completely.

At the end of 24 hours, operate the equipment for at least 10 minutes while it is completely immersed in the fluid.

Following this period, remove the test specimen, place in an appropriate chamber and subject it to a constant temperature of +65 degrees C for minimum of 160 hours. At the end of this period, the test specimen shall be returned to room temperature and operated for a minimum of two hours.

Following the two-hour period, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

At the completion of the test, the equipment shall be inspected and shall show no evidence of damage of any internal or external component.

11.5 Use of Material Specimens

Material specimen test may be used in place of equipment tests. The results of these tests shall assure that the material will protect the equipment from deleterious effects after being exposed to the relevant fluid in the manner defined in the equipment test procedures (Subsection 11.4).

Note: Material specimen tests are not permitted if the equipment is to be subsequently subjected to the continuous stream proof test (paragraph 10.3.3).

Table 11-1 Classes of Test Fluids and Fluid Temperatures

Class of Contaminating Fluid	Test Fluid	Fluid Temperature Degrees C
Fuels	Aviation Jet A Fuel Aviation Piston Engine Fuel	40 <u>1</u> / 40 <u>1</u> /
Hydraulic Fluids	Mineral-Based Non-mineral Based Phosphate Ester-Based (Synthetic), Type IV <u>2</u> / Silicate Ester-Based (Synthetic) Silicone-Based (Synthetic) Synthetic Hydrocarbon Base	80 50 70 70 70 70
Lubricating Oils	Mineral-Based Ester-Based (Synthetic) Internal Combustion Engine 15W40	70 150 70
Solvents and Cleaning Fluids	Isopropyl Alcohol Denatured Alcohol Cleaning compound for aircraft surfaces Trans-1-2Dichloroethylene (replacement for 1,1,1 Trichloroethylene)	50 <u>1</u> / 23 <u>1</u> / 23 23
De-Icing Fluid	Ethylene Glycol Propylene Glycol AEA Type 1 <u>3</u> / AEA Type 2 <u>3</u> / SAE Type 1 SAE Type 2 SAE Type 4	50 50 50 50 23 23 23
Insecticides	Dichlorvos (DDVP) (commercially available min 0.92% concentration by volume) Pyrethroid Pesticide (commercially available min 0.92 concentration by volume)	23 23
Sullage	To be defined by the equipment specification	23
Disinfectant (Heavy duty Phenolics)	Clear, soluble phenolics, e.g., phenol or its derivatives dissolved in surfactant and diluted with water to give a clear solution. Black fluids, e.g., refined tar products dissolved in a carrier oil and emulsified with detergent. White fluids, e.g., colloidal emulsions of refined coal tar products in water, usually containing a small amount of surfactant.	23 23 23
Coolant dielectric fluid	PAO dielectric	70

Fire extinguishants	Protein	23
	Fluoroprotein	23
	Aqueous Film Forming Foam (ATTF)	23

NOTES – For Table 11-1:

- 1/ This temperature exceeds the critical flash point temperature. Testing should always be performed in a suitable pressure vessel.
- 2/ These fluids are electrically conductive. Suitable precautions should be taken after exposure to the fluids before operating the equipment.
- 3/ Association of European Airlines.

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 12

Sand and Dust

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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12.0 Sand and Dust**12.1 Purpose of the Test**

This test determines the resistance of the equipment to the effects of blowing sand and dust where carried by air movement at moderate speeds. The main adverse effects to be anticipated are:

- a. Penetration into cracks, crevices, bearings and joints, causing fouling and/or clogging of moving parts, relays, filters, etc.
- b. Formation of electrically conductive bridges.
- c. Action as nucleus for the collection of water vapor, including secondary effects of possible corrosion.
- d. Pollution of fluids.

NOTE: Consideration must be given in determining where in the sequence of environmental tests to apply this test procedure, as dust residue from this test procedure, combined with other environmental synergistic effects may corrode or cause mold growth on the test item and adversely influence the outcome of succeeding test procedures. Sand abrasion may also influence the results of the salt spray, fungus or humidity test procedures.

12.2 Categories of EquipmentCategory D

Equipment tested as recommended in the following paragraphs for Dust test is identified as Category D. Such equipment can be installed in locations where the equipment is subjected to blowing dust in the course of normal aircraft operations.

Category S

Equipment tested as recommended in the following paragraphs for both Dust test and Sand test is identified as Category S. Such equipment can be installed in locations where the equipment is subjected to blowing sand and dust in the course of normal aircraft operations. Such location includes cockpit or any other location not intentionally protected against sand and dust exposure.

12.3 Agent**12.3.1 Dust**

Dust used in a suitable test chamber vented to the atmosphere shall be raised and maintained at a concentration of 3.5 to 8.8 g/m³ and shall be 97% to 99% silicon dioxide.

Dust to be used can be Red china clay or Silica Flour and must meet size distributions of 100% by weight less than 150 µm, with a median diameter (50 ± 2 % by weight) of 20 ± 5 µm. This dust is readily available as a 140 mesh Silica Flour (about 2% retained on a 140 mesh (108 microns) sieve) and should provide comparable results to prior test requirements. National documentation may contain other more specific distributions.

12.3.2 Sand

(1) If sand concentration data is available for the worst case field environment the equipment is expected to properly function in, then test to that sand concentration level.

(2) For materiel likely to be used close to helicopters operating over unpaved surfaces: 2.2 +/- 0.5 g/m³ (0.06 +/- 0.015 g/per cubic foot).

(3) For material never used or exposed in the vicinity of operating aircraft, but which may be used or stored unprotected near operating surface vehicles: 1.1 +/- 0.3 g/m³ (0.033 +/- 0.0075 g/per cubic foot).

(4) For material that will be subjected only to natural conditions: 0.18 g/m³, -0.0/+0.2 g/m³ (0.005 g/per cubic foot). (This large tolerance is due to the difficulties of measuring concentrations at low levels.).

Unless otherwise specified, for the sand test use silica sand (at least 95 percent by weight SiO₂). Use sand of sub-angular structure, a mean Krumbein number range of 0.5 to 0.7 for both roundness and sphericity and a hardness factor of 7 mhos. Due to the loss of subangular structure and contamination, re-use of test sand is normally not possible. The recommended particle size distribution for the large particle sand test is from 150 µm to 850 µm, with a mean of 90 ±5 percent by weight smaller than 600 µm and larger than or equal to 150 µm, and at least 5 percent by weight 600 µm and larger.

12.4 Dust Test Procedure

The equipment shall be submitted to the dust test along each direction of each major orthogonal axis in succession. The air velocity shall be maintained between 0.5 and 2.4 m/second.

***Note 1:** Unless otherwise required in the relevant specification, the equipment is not required to operate during the exposure period.*

***Note 2:** Health and safety regulations regarding the use of dust should be observed.*

12.4.1 First Cycle

With the internal temperature of the test chamber maintained at +25 ±2 degrees Celsius (°C) and the relative humidity at not more than 30 percent, submit the equipment to a minimum exposure period of one hour along each direction of each major orthogonal axis in succession.

12.4.2 Second Cycle

With the internal temperature of the test chamber raised and stabilized at +55 ±2 °C and the relative humidity at not more than 30 percent, submit the equipment to a minimum exposure period of one hour along each direction of each major orthogonal axis in succession.

At the end of this exposure period, the equipment shall be removed from the chamber and cooled to room temperature. Externally accumulated dust only on surfaces of the equipment required to verify proper operation (e.g. displays, connectors, keyboards, test ports etc.) shall be removed by brushing, wiping or shaking with care being taken to avoid introducing additional dust into the equipment. Under no circumstances shall dust

be removed by either air blast or vacuum cleaning. After removing the excess dust, manipulate the mechanical moving features of the equipment ten times and check for clogging or binding of movement. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

12.5 Sand Test Procedure

The test item shall be submitted to the sand test at wind velocities ranging from 18-29 m/s, with the exposed surface positioned 3-m from the sand injection point - to allow sand particles to reach terminal wind velocities before impacting the test item. If the test item will not directly see wind velocities of this magnitude during normal service life (cockpit screen displays) then the test item shall be submitted to air velocities of 0.5 and 2.4 m/second. A vertical chamber may be utilized to preserve the uniformity of sand distribution.

Note 1: Unless otherwise required in the relevant specification, the equipment is not required to operate during the exposure period.

12.5.1 First Cycle

With the internal temperature of the test chamber maintained at $+25 \pm 2$ °C and the relative humidity at not more than 30 percent, submit the equipment to a minimum exposure period of one hour along each direction of each major orthogonal axis in succession.

12.5.2 Second Cycle

With the internal temperature of the test chamber raised and stabilized at $+55 \pm 2$ °C and the relative humidity at not more than 30 percent, submit the equipment to a minimum exposure period of one hour along each direction of each major orthogonal axis in succession.

At the end of this exposure period, the equipment shall be removed from the chamber and cooled to room temperature. Externally accumulated sand only on surfaces of the equipment required to verify proper operation (e.g. displays, connectors, keyboards, test ports etc.) shall be removed by brushing, wiping, or shaking with care being taken to avoid introducing additional sand into the equipment. Under no circumstances shall sand be removed by either air blast or vacuum cleaning. After removing the excess sand, manipulate the mechanical moving features of the equipment ten times and check for clogging or binding of movement. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 13

Fungus Resistance

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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13.0 Fungus Resistance**13.1 Purpose of the Test**

These tests determine whether equipment material is adversely affected by fungi under conditions favorable for their development, namely, high humidity, warm atmosphere and presence of inorganic salts.

Notes:

- A. Fungi proximity to other materials, exposure to daily susceptible contaminants such as fluids during routine operation and maintenance, or equipment exposure to solar actinic effects - may break molecular bonds and reduce the item to sub-compositions which may be fungus nutrients.*
- B. This test shall not be conducted after Salt Spray or Sand and Dust. A heavy concentration of salt may effect the fungal growth, and sand and dust can provide nutrients, which could compromise the validity of this test (see Subsection 3.2, "Order of Tests").*

13.2 General Effects

Typical problems caused by fungi growing on equipment are:

- a. Microorganisms digest organic materials as a normal metabolic process, thus degrading the substrate, reducing the surface tension and increasing moisture penetration.
- b. Enzymes and organic acids, produced during metabolism, diffuse out of the cells and onto the substrate and cause metal corrosion, glass etching, hardening of grease and other physical and chemical changes to the substrates.
- c. The physical presence of microorganisms produces living bridges across components that may result in electrical failures.
- d. The physical presence of fungi can also cause health problems and produce aesthetically unpleasant situations in which users will reject using the equipment.

The detrimental effects of fungal growth are summarized as follows:

- a. Direct attack on materials. Nonresistant materials are susceptible to direct attack as fungus breaks these materials down and uses them as nutrients. This results in deterioration affecting the physical properties of the material. Examples of nonresistant materials are:
 - (1) Natural material. Products of natural origin (carbon based) are most susceptible to this attack.
 - (a) Cellulose materials (e.g., wood, paper, natural fiber textiles, and cordage).
 - (b) Animal- and vegetable-based adhesives.

- (c) Grease, oils, and many hydrocarbons.
- (d) Leather.
- (2) Synthetic materials.
- (a) PVC formulations (e.g., those plasticized with fatty acid esters).
- (b) Certain polyurethanes (e.g., polyesters and some polyether).
- (c) Plastics that contain organic fillers of laminating materials.
- (d) Paints and varnishes that contain susceptible constituents.

b. Indirect attack on materials. Damage to fungus-resistant materials results from indirect attack when:

- (1) Fungal growth on surface deposits of dust, grease, perspiration, and other contaminants (that find their way onto materiel during manufacture or accumulate during service) causes damage to the underlying material, even though that material may be resistant to direct attack.
- (2) Metabolic waste products (i.e., organic acids) excreted by fungus cause corrosion of metals, etching of glass, or staining or degrading of plastics and other materials.
- (3) The acidic waste products of fungus on adjacent materials that are susceptible to direct attack come in contact with the resistant materials.

13.3 Categories of Equipment

Category F

Equipment that is installed in an environment where it will be exposed to severe fungus contamination is identified as Category F and shall be subjected to the fungus resistance test. If all materials used in the construction of the equipment can be shown to be non-nutrients for the growth of fungi, either through their composition or through previous testing, this test is not required. If non-nutrient material certification is utilized for this verification, this fact shall be declared on the Environmental Qualification Form (see Appendix A).

13.4 Apparatus

The apparatus required to conduct this test consists of chambers or cabinets together with auxiliary instrumentation capable of maintaining the specified condition of temperature and humidity. Provisions shall be made to prevent condensation from dripping on the test item. There shall be free circulation of air around the test item and the contact area of fixtures supporting the test item shall be kept to a minimum. When forced air is employed, the flow should not exceed one meter per second over the surface of the test specimen.

13.5 Test Procedures

13.5.1 Preparation of Mineral-Salts Solution

The solution shall contain the following:

Potassium dihydrogen orthophosphate	0.7 g
Potassium monohydrogen orthophosphate	0.7 g
Magnesium sulfate heptahydrate	0.7 g
Ammonium nitrate.....	1.0 g
Sodium chloride.....	0.005 g
Ferrous sulfate heptahydrate	0.002 g
Zinc sulfate heptahydrate.....	0.002 g
Manganous sulfate monohydrate	0.001 g
Distilled Water.	1000 ml

Sterilize the mineral salts solution by autoclaving at 121 degrees C for 20 minutes. Adjust the pH of the solution by the addition of 0.01 normal solution of sodium hydroxide so that after sterilization the pH level is between 6.0 and 6.5. Prepare sufficient salt solutions for the required tests.

13.5.1.1 Purity of Reagents

Reagent grade chemicals shall be used in all tests. Unless otherwise specified, it is intended that all reagents shall conform to the specification of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.

13.5.1.2 Purity of Water

Unless otherwise specified, references to water shall be understood to mean distilled water or water of equal purity.

13.5.2 Preparation of Mixed Spore Suspension

The following test fungi shall be used:

<u>Fungi</u>	<u>ATCC¹</u>
Aspergillus niger	9642
Aspergillus flavus	9643
Aspergillus versicolor	11730
Penicillium funiculosum	11797
Chaetomium globosum	6205

¹

American Type Culture Collection, 12301 Parklawn Drive, Rockville, Maryland, 20852.

Maintain cultures of these fungi separately on an appropriate medium such as potato dextrose agar. However, the culture of *Chaetomium globosum* shall be cultured on strips of filter paper on the surface of mineral salts agar. (Mineral salts agar is identical to the mineral salts solution described in paragraph 13.5.1, but contains in addition 15.0 g of agar/liter.) The stock cultures may be kept for not more than four months at 6 ± 4 degrees C, at which time subcultures shall be made and new stocks shall be selected from the subcultures. If genetic or physiological changes occur, obtain new cultures as specified above. Subcultures used for preparing new stock cultures or the spore suspension shall be incubated at 30 degrees C for seven to ten days. Prepare a spore suspension of each of the five fungi by pouring into one subculture of each fungus a 10 ml portion of a sterile solution containing 0.05 g/liter of a non-toxic wetting agent such as sodium dioctyl sulfosuccinate or sodium lauryl sulfate. Use a sterile platinum or nichrome inoculating wire to scrape gently the surface growth from the culture of the test organism. Pour the spore charge into a sterile 125 ml glass-stoppered Erlenmeyer flask containing 45 ml of sterile water and 10 to 15 solid glass beads, five millimeters in diameter. Shake the flask vigorously to liberate the spores from the fruiting bodies and to break the spore clumps. Filter the dispersed fungal spore suspension through a six millimeter layer of glass wool, contained in a glass funnel, into a sterile flask. This process should remove large mycelial fragments and clumps of agar that could interfere with the spraying process. Centrifuge the filtered spore suspension aseptically and discard the supernatant. Resuspend the residue in 50 ml of sterile water and centrifuge. Wash the spores obtained from each of the fungi in this manner three times. Dilute the final washed residue with sterile mineral-salts solution in such a manner that the resultant spore suspension shall contain $1,000,000 \pm 200,000$ spores/milliliter as determined with a counting chamber. Repeat this operation for each organism used in the test and blend equal volumes of the resultant spore suspension. The spore suspension may be prepared fresh each day and maintained at 6 ± 4 degrees C not more than fourteen days.

13.5.3 Viability of Inoculum Control

With each daily group of tests, place each of three pieces of sterilized filter paper, 2.54 cm square on hardened mineral-salts agar in separate Petri dishes. Inoculate these with the spore suspension by spraying the suspension from a sterilized atomizer¹ until initiation of droplet coalescence. Incubate these at 30 degrees C at a relative humidity not less than 85 percent, and examine them after seven days of incubation. There shall be copious growth on all three of the filter paper control specimens. Absence of such growth requires repetition of the test.

13.5.4 Control Items

In addition to the viability of inoculum control, known susceptible substrates shall be inoculated along with the test item to insure that proper conditions are present in the incubation chamber to promote fungus growth. The control items shall consist of (unbleached) cotton duck 234 g strips that are 3.2 cm wide, that have been dipped into a solution containing 10% glycerol, 0.1% potassium dihydrogen orthophosphate, 0.1% ammonium nitrate, 0.025% magnesium sulfate, and 0.05% yeast extract (pH level 5.3), and from which the excess liquid has been removed. The strips should be hung to air dry before being inoculated and placed into the chamber.

13.5.5 Inoculation of Test Control

- a. Mount the test and control items on suitable fixtures or suspend from hangers.
- b. Precondition the chamber and its contents at 30 degrees C and 97 $\pm$ 2% relative humidity for at least four hours.
- c. Inoculate the test and control items with the mixed fungus spore suspension (paragraph 13.5.2) by spraying it on the test and control items in the form of a fine mist from a previously sterilized atomizer or nebulizer. In spraying the test and control items, care should be taken to cover all surfaces. If the surfaces are non-wetting, spray until initiation of droplet coalescence. Incubation is to be started immediately following the inoculation.

13.5.6 Incubation

- a. Maintain the test chamber at 30 degrees C and 97 $\pm$ 2% relative humidity (minimum) during the life of the test. Keep the test chamber closed during the incubation period, except during inspection or for addition of other test items.
- b. After seven days, inspect the growth on the control items to be assured that the environmental conditions are suitable for growth. If inspection reveals that the environmental conditions are unsuitable for growth, the entire test shall be repeated.
- c. If the control items show satisfactory fungus growth, continue the test for a period of 28 days from the time of inoculation or as specified in the equipment specification.

¹ An atomizer capable of providing 15,000 $\pm$ 3,000 spores/cm².

13.5.7 Inspection

At the end of the incubation period, inspect the test item immediately. If possible, inspect the item within the chamber. If the inspection is not completed in eight hours, return the test item to the humid environment for a minimum of twelve hours. Except for hermetically sealed equipment, open the equipment enclosure and examine both the interior and exterior for evidence of deterioration. The equipment shall then be tested to DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

13.5.7.1 Analysis of Results.

The following information is provided to assist in the evaluation of the test results.

- a. Any fungal growth on the test item must be analyzed to determine the species, and if the growth is on the test item material(s) or on contaminants.
- b. Any fungal growth on the test item material(s), whether from the inoculums or other sources, must be evaluated by qualified personnel for:
 - (1) The extent of growth on susceptible components or materials. Any growth must be completely described.
 - (2) The immediate effect that the growth has on the physical characteristics of the materiel.
 - (3) The long-range effect that the growth could have on the materiel.
 - (4) The specific material (nutrient(s)) supporting the growth.
- c. Evaluate human factors effects (including health risks).

13.5.8 Precautions

The fungi specified for this test are not normally considered a serious hazard for human handling. It is possible for an individual to be allergic to one of them, and for this reason it is wise to exercise care when performing the test. Surgical gloves may be worn to protect the hands, and care should be taken not to splash the suspension on other areas of the skin or on clothes. Additionally, an advisory prior to fungus inoculation should be issued instructing personnel possibly entering the vicinity where fungus spray inoculations or test preparations are taking place, to wear surgical masks and gloves as precautions to prevent adverse health reactions from fungus exposure.

It is also possible, during the incubation period in the test chamber, for a foreign spore, present as an unintentional intruder, to develop; some of these fungi thus present as native to some testing locations, may be injurious to the human system. For this reason there is a possibility that the specimen after exposure may be a hazard, and it should be handled with care.

The greatest danger, if some hazardous foreign spore is present on exposed specimens, is that small, dry, detached particles may become airborne and be carried into the lungs. This is only likely to happen after the specimen has dried out. If the specimen is carried quickly from the test chamber to a normal chemical fume hood before it has time to dry,

the flow of air does not reach the operator and detached fragments cannot enter the nasal passages.

Detached portions of growth may be so small that no protection is offered by wearing a gauze mask and only a special respirator for sub-micron particles is effective. The use of a fume hood as suggested above, however, is considered an adequate precaution when performing this test.

Where the test location may contain such a harmful fungus, vestiges of it may remain in the test chamber and present a similar danger when it is being cleansed. High temperature steam, the preferred cleansing treatment, will render the chamber completely harmless. Where, however, fumigation with propylene oxide is adopted, it will be noted that fumigation prior to washing will ensure that all residues washed from the chamber are completely harmless.

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 14

Salt Fog

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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14.0 Salt Fog

14.1 Purpose of the Test

This test determines the effects on the equipment of prolonged exposure to a salt atmosphere or to salt fog experienced in normal operations.

The main adverse effects to be anticipated are:

- a. Corrosion of metals.
- b. Clogging or binding of moving parts as a result of salt deposits.
- c. Insulation fault.
- d. Damage to contacts and uncoated wiring.

Note: The salt fog test shall not be conducted prior to the fungus resistance test (see Subsection 3.2, “Order of Tests”).

14.2 Categories of Equipment

Category S

When the equipment is installed in locations where it is subjected to a corrosive atmosphere in the course of normal aircraft operations, the equipment is identified as Category S and the salt fog test is applicable.

Category T

When the equipment is installed in locations where it is subjected to a severe salt atmosphere, such as equipment exposed directly to external unfiltered air on hovering aircraft that may operate or be parked near the sea, the equipment is identified as category T and the severe salt fog test is applicable..

14.3 Apparatus

The apparatus used in the salt fog test shall include the following:

- a. Exposure chamber with racks for supporting test items.
- b. A salt solution reservoir with means for maintaining an adequate level of solution.
- c. A means for atomizing the salt solution, including suitable nozzles and compressed air supply.
- d. A means of heating and controlling chamber temperature.
- e. A means for humidifying the air at temperatures above the chamber temperature.

14.3.1 Chamber

The chamber and all accessories shall be made of material that will not affect the corrosiveness of the fog, e.g. glass, hard rubber, plastic or kiln-dried wood other than plywood. In addition, all parts that come in contact with test items shall be made of materials that will not cause electrolytic corrosion. The chamber and accessories shall be constructed and arranged so that there is no direct impingement of the fog or dripping of the condensate on the test items; the fog circulates freely about all test items to the same degree, and no liquid that has come in contact with the test item returns to the salt-solution reservoir. The chamber shall be properly vented to prevent pressure build-up and allow uniform distribution of the salt fog. The discharge end of the vent shall be protected from strong drafts to prevent strong air currents in the test chamber.

14.3.2 Atomizers

The atomizers shall be designed and constructed to produce a finely divided, wet, dense fog. Atomizing nozzles shall be made of materials that are non-reactive to the salt solution.

14.3.3 Air Supply

The compressed air entering the atomizers shall be essentially free from all impurities, such as oil and dirt. Means shall be provided to humidify and warm the compressed air as required to meet the operating conditions. The air pressure shall be suitable to produce a finely divided dense fog with the atomizer or atomizers used. To avoid clogging the atomizers with salt deposition, the air should have a relative humidity of at least 85 percent at the point of release from the nozzle. A satisfactory method is to pass the air in very fine bubbles through a tower containing heated water that is automatically maintained at a constant level. The temperature of the water should be at least 35 degrees C. The permissible water temperature increases with the increasing volume of air and with the decreasing heat insulation of the chamber and the chamber's surroundings. However, the temperature should not exceed a value above which excessive moisture is introduced into the chamber (for example 43 degrees C at an air pressure of 84 kPa) or a value that makes it impossible to meet the requirements for operating temperature.

14.3.4 Preparation of Salt Solution

The salt shall be sodium chloride containing on the dry basis not more than 0.1 percent sodium iodide and not more than 0.5 percent of total impurities. Unless otherwise specified, a five $\pm$ 1 percent solution shall be prepared by dissolving five parts by weight of salt in 95 parts by weight of distilled or demineralized water. The solution shall be adjusted to and maintained at a relative density between the limits shown on Figure 14-1 by utilizing the measured temperature and density of the salt solution.

14.3.4.1 Adjustment of pH

The pH of the salt solution shall be maintained and measured daily so that the solution atomized at 35°C and collected by the method specified in subparagraph 14.3.6.3 will be in the pH range of 6.5 to 7.2. Only diluted chemically pure hydrochloric acid or chemically pure sodium hydroxide shall be used to adjust the pH. The pH measurement shall be made electrometrically, using a glass electrode with a saturated potassium chloride bridge, by a colorimetric method such as bromothymol blue or other measuring instruments or litmus paper, provided the results are equivalent to those obtained with the electrometric method. The pH shall be measured when preparing each new batch of solution and as specified in subparagraph 14.3.6.4.

14.3.5 Filter

A filter fabricated of noncorrosive materials similar to that shown in [Figure 14-2](#) shall be provided in the supply line and immersed in the salt solution reservoir as illustrated in [Figure 14-2](#).

14.3.6 Test Procedure**14.3.6.1 Temperature**

The test shall be conducted with a temperature in the exposure zone maintained at 35 degrees C. Satisfactory methods for controlling the temperature accurately are by housing the apparatus in a properly controlled constant temperature room, by thoroughly insulating the apparatus and preheating the air to the proper temperature prior to atomization or by jacketing the apparatus and controlling the temperature of the water or of the air used in the jacket. The use of immersion heaters within the chamber for the purpose of maintaining the temperature within the exposure zone is prohibited.

14.3.6.2 Atomization

Suitable atomization has been obtained in chambers having a volume of less than 0.34 m³ with the following conditions:

- a. Nozzle pressure shall be as low as practical to produce fog at the required rate.
- b. Orifices shall be between 0.5 mm and 0.8 mm in diameter.
- c. Atomization of approximately three liters of salt solution per 0.28 m³ of chamber volume per 24 hours.

When using large size chambers having a volume considerably in excess of 0.34 m³, the condition specified may require modification to meet the requirements for operating conditions.

14.3.6.3 Placement of Salt Fog Collection Receptacles

The salt fog conditions maintained in all parts of the exposure zone shall be such that a clean fog-collecting receptacle placed at any point in the exposure zone will collect from 1 to 3 milliliters of solution per hour for each 80 cm² of horizontal collecting area (10 cm diameter) based on an average test of at least 16 hours. A minimum of two receptacles shall be used, one placed at the perimeter of the test item nearest to the nozzle, and the other also at this perimeter of the test item but at the farthest point from the nozzle. Receptacles shall be placed so that they are not shielded by test items and so that drops of solution from test items or other sources will not be collected.

14.3.6.4 Measurement of Salt Solution

The solution, collected in the manner specified in subparagraph 14.3.6.3, shall have the sodium chloride content and pH specified in paragraph 14.3.4 when measured at a temperature of 35 degrees C. The salt solution from all collection receptacles used can be combined to provide the quantity required for the measurements specified.

14.3.6.4.1 Measurement of Sodium Chloride Content

The solution, maintained at the specified temperature, can be measured in a graduate of approximately 2.5 cm inside diameter. A small laboratory type hydrometer will be required for measurement within this volume.

14.3.6.4.2 Measurement of pH

The pH shall be measured as specified in paragraph 14.3.4.1.

14.3.6.4.3 Time of Measurements

The measurement of both sodium chloride and pH shall be made at the following times:

- a. For salt fog chambers in continuous use, i.e., used within five days, the measurements shall be made following each test.
- b. For salt fog chambers that are used infrequently, more than five days since use or if nozzles have been clogged, a 24-hour test run shall be accomplished followed by the measurements. The test item shall not be exposed to this test run.

14.3.6.5 Preparation of Test Item

The test item shall receive minimum handling, particularly on the significant surfaces, and shall be prepared for test immediately before exposure. Unless otherwise specified, uncoated metallic or metallic-coated devices shall be thoroughly cleaned of oil, dirt and grease as necessary until the surface is free from water break. The cleaning methods shall not include the use of corrosive or protective films, nor the use of abrasives other than a paste of pure magnesium oxide. Test items having an organic coating shall not be cleaned with a solvent. Those portions of test items which come in contact with the support and, unless otherwise specified in the case of coated devices or samples, cut edges and surfaces not required to be coated, shall be protected with a suitable coating of wax or similar substance impervious to moisture.

14.3.6.6 Performance of Normal Salt Fog Test (Category S)

Step 1: Continuously atomize a salt solution of a composition as given in 14.3.4 into the test chamber for a period of 24 hours or as specified in the test plan. During the entire exposure period measure the salt fog fallout rate and pH of the fallout solution at least at 24-hour intervals^{1/}. Ensure the fallout is between 1 and 3 ml/80cm²/hr.

Step 2: Dry the test item at standard ambient temperatures and a relative humidity of 50% or less for 24 hours. Do not disturb the test item or adjust any mechanical features during the drying period.

Step 3: At the end of the drying period and unless otherwise specified, replace the test item in the salt fog chamber and perform one repeat of steps 1 and 2.

Step 4: At the end of the drying period, operate the test item and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The test item shall then be inspected for corrosion. If necessary, a gentle wash in running water not warmer than 28 degrees C may be used. Any corrosion must be analyzed for its immediate or potential effect on proper functioning of the test item.

14.3.6.7 Performance of the Severe Salt Fog test (Category T)

Step 1: Continuously atomize a salt solution of a composition as given in 14.3.4 into the test chamber for a period of 48 hours or as specified in the test plan. During the entire exposure period measure the salt fog fallout rate and pH of the fallout solution at least at 24-hour intervals^{2/}. Ensure the fallout is between 1 and 3 ml/80cm²/hr.

Step 2: Dry the test item at standard ambient temperatures and a relative humidity of 50% or less for 24 hours. Do not disturb the test item or adjust any mechanical features during the drying period.

Step 3: At the end of the drying period and unless otherwise specified, replace the test item in the salt fog chamber and perform one repeat of steps 1 and 2.

Step 4: Within an hour of removing the equipment from the chamber, power the equipment and allow to dry for 24 hours. Then DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The test item shall then be inspected for corrosion. Before any dismantling or washing operation, measure and record the insulation or bonding values as defined in the equipment specification. Then, if necessary, a gentle wash in running water not warmer than 28 degrees C may be used. Any corrosion must be analyzed for its immediate or potential effect on proper functioning of the test item.

14.3.6.8 Failure Considerations

^{1/} Recommend more frequent intervals. Repeat the interval if fallout quantity requirements are not met.

^{2/} Recommend more frequent intervals. Repeat the interval if fallout quantity requirements are not met.

- a. Physical. Salt deposits can cause clogging or binding of mechanical components and assemblies. The extent of any deposits resulting from this test may be representative of those induced by anticipated environments.
- b. Electrical. Moisture remaining after the 24-hour drying period could cause electrical malfunctions. If so, attempt to relate the malfunctions to that possible in service.
- c. Corrosion. Analyze any corrosion for its immediate and potential long-term effects on the proper functioning and structural integrity of the test item.

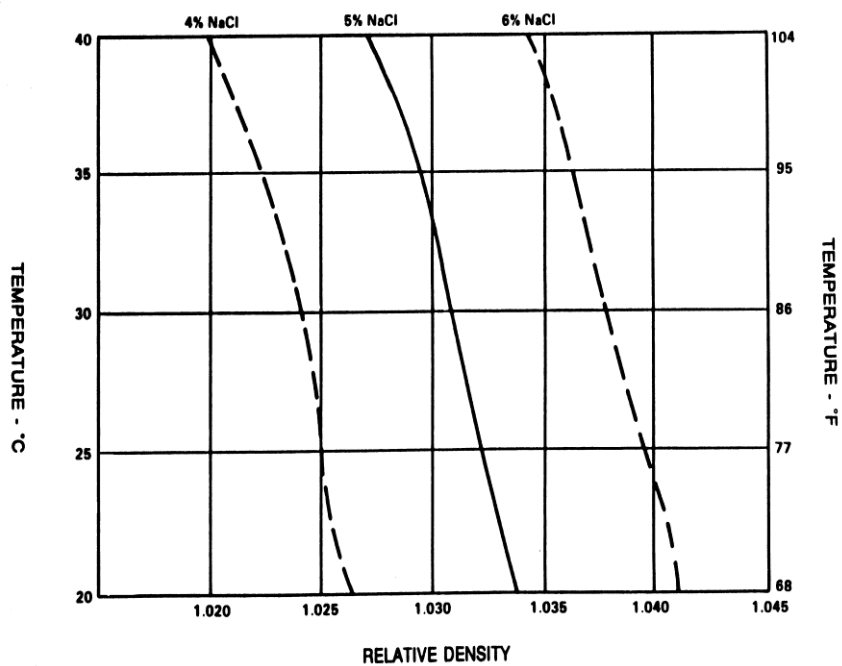


Figure 14-1 Relative Density Variations of the Salt Solution with Temperature

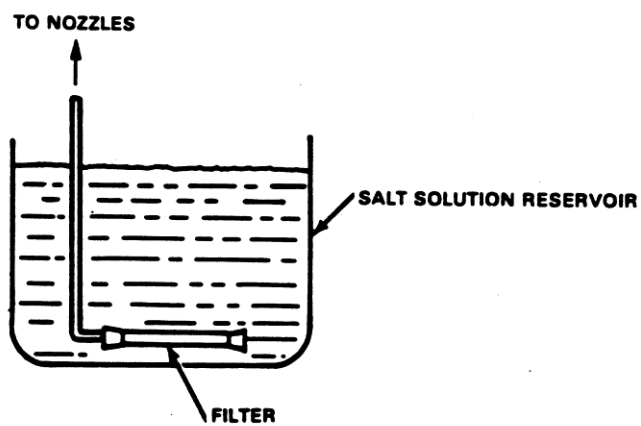
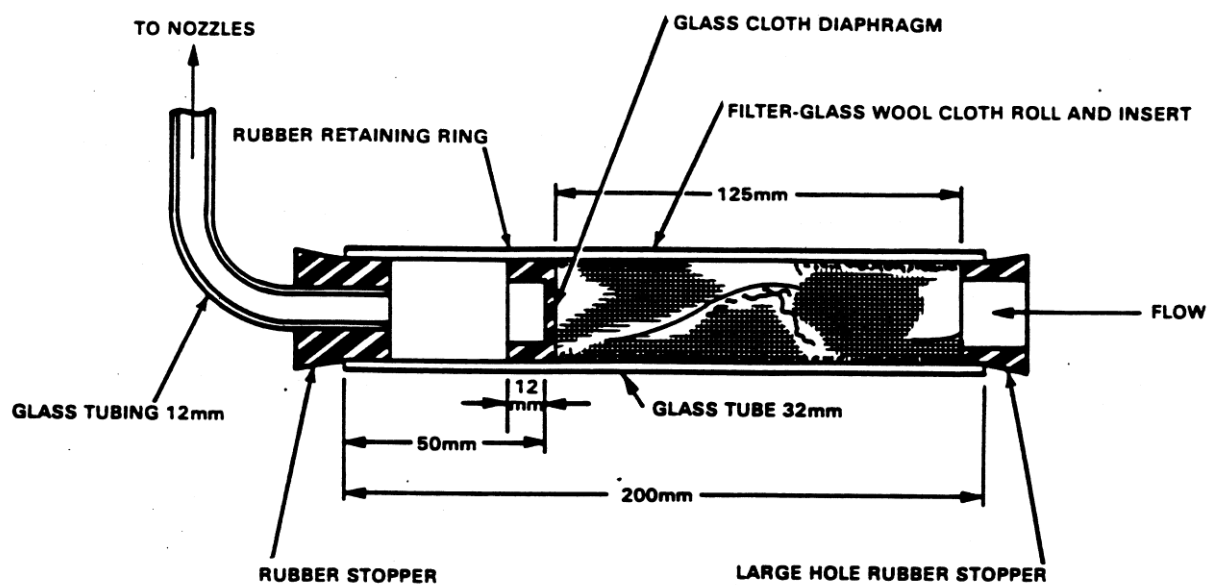


FIGURE 14-2
LOCATION OF SALT SOLUTION FILTER

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 15

Magnetic Effect

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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15 Magnetic Effect

15.1 Purpose of the Test

This test determines the magnetic effect of the equipment and is mainly intended for finding or proving the closest distance to compasses or compass sensors (flux gates) at which that unit is allowed to be installed. This test ensures that equipment can operate properly without interference which may affect the nearby equipment, determining equipment compliance with the applicable equipment performance standard or assisting the installer in choosing the proper location of the equipment in the aircraft.

With D being the distance at which the 1 degree (1°) deflection is observed, the following category designation is given to the equipment:

- Category Y: $D = 0.0\text{m}$. The deflection of the compass is $\leq 1^\circ$ when measured immediately adjacent to the equipment. This category should be used for equipment whose installation is placed between 0.0m and 0.3m from the magnetic compasses or flux gates.
- Category Z: $0 < D \leq 0.3\text{m}$. The deflection of the compass is equal to 1° when measured $>0.0\text{m}$ to $\leq 0.3\text{m}$ to the equipment. This category should be used for equipment whose installation is $\geq 0.3\text{m}$ to magnetic compasses or flux gates.
- Category A: $0.3 < D \leq 1\text{m}$. The deflection of the compass is equal to 1° when measured $>0.3\text{m}$ to $\leq 1.0\text{m}$ to the equipment. This category should be used for equipment whose installation is $\geq 1\text{m}$ to magnetic compasses or flux gates.
- Category B: $1\text{m} < D \leq 3\text{m}$. The deflection of the compass is equal to 1° when measured $>1.0\text{m}$ to $\leq 3.0\text{m}$ to the equipment. This category should be used for equipment whose installation is $\geq 3\text{m}$ to magnetic compasses or flux gates.
- Category C: The deflection of the compass is equal to 1° when measured $>3.0\text{m}$ to the equipment. This category should be used for equipment whose installation is $>3\text{m}$ to magnetic compasses or flux gates. Minimum distance for deviation of 1° shall be reported in the test form; the equipment location onboard will be selected accordingly.

15.2 Test Description

The magnetic effect of the equipment shall be determined in terms of the equivalent deflection of a free magnet in a uniform magnetic field (as produced by the earth) having a horizontal intensity of $14.4\text{ A/m} \pm 10\%$ when the equipment under test is positioned on the east-west line through the pivot of a magnet. This measurement may be performed with either an uncompensated compass or an equivalent magnetic sensor.

Note 1: If the horizontal component of the magnetic field produced by the earth at the location of the test lab is within the tolerance stated above, the angular deflection used to determine equipment category in paragraph 15.3 shall be one degree ($D_c = 1$).

Note: 2: If the horizontal component of the magnetic field produced by the earth at the location of the test lab exceeds the tolerance stated above, the angular deflection used to determine the equipment category in Subsection 15.3 shall be adjusted using the following formula:

$$D_c = \frac{14.4 \text{ A/m}}{\text{Horizontal Component of Ambient Field Strength}}$$

where,

D_c is the equivalent deflection angle to be used in determining equipment category.

15.3 Test Procedure

The EUT is to be powered with the same or an identical cable harness used for section 20 testing. All cables and extended power leads for the EUT are to be placed in one bundle for the test. This bundle is to be routed along the east to west axis of the compass.

- 1) If HCAFS (HCAFS = Horizontal Component of Ambient magnetic Field Strength produced by the earth) at the location of the test lab without EUT is unknown, measure it (with magnetometer for instance).
- 2) If HCAFS is within the tolerances described in paragraph 15.2, then $D_c = 1^\circ$ per paragraph 15.2, NOTE 1.

If HCAFS is not within the tolerances described in paragraph 15.2, adjust the value of the deflection angle (D_c) by inserting the measured HCAFS into the formula given in paragraph 15.2, NOTE 2.

- 3) Place the EUT cable on the east - west line through the pivot of a magnet as shown in Figure 15-1.
- 4) With the EUT operating, choose the steady state mode that produces the maximum magnet deflection.
- 5) With the EUT cable maintained on the east-west line through the pivot of a magnet, choose the orientation of the EUT that produces the maximum magnet deflection.
- 6) Reduce the distance between the EUT and the magnet to obtain D_c .

If the test is performed by moving the compass towards the EUT rather than moving the EUT towards the compass, then a field uniformity test is necessary. This test is performed as follows:

With the EUT removed from the test area, the compass shall not deflect by more than +/- 0.5 degrees with the compass moved linearly along the planned path to the EUT location.

- 7) Measure and record the minimum distance between the magnet pivot and the nearest part of the EUT obtained for D_c .
- 8) Using the measured distance D for a deflection of D_c from step 7, select the category from the table below:

<u>Equipment Category</u>	<u>Distance for a Deflection of D_c</u>
Y	$D = 0.0\text{m}$
Z	$0 < D \leq 0.3\text{m}$
A	$0.3 < D \leq 1\text{m}$
B	$1\text{m} < D \leq 3\text{m}$
C	greater than 3.0 m

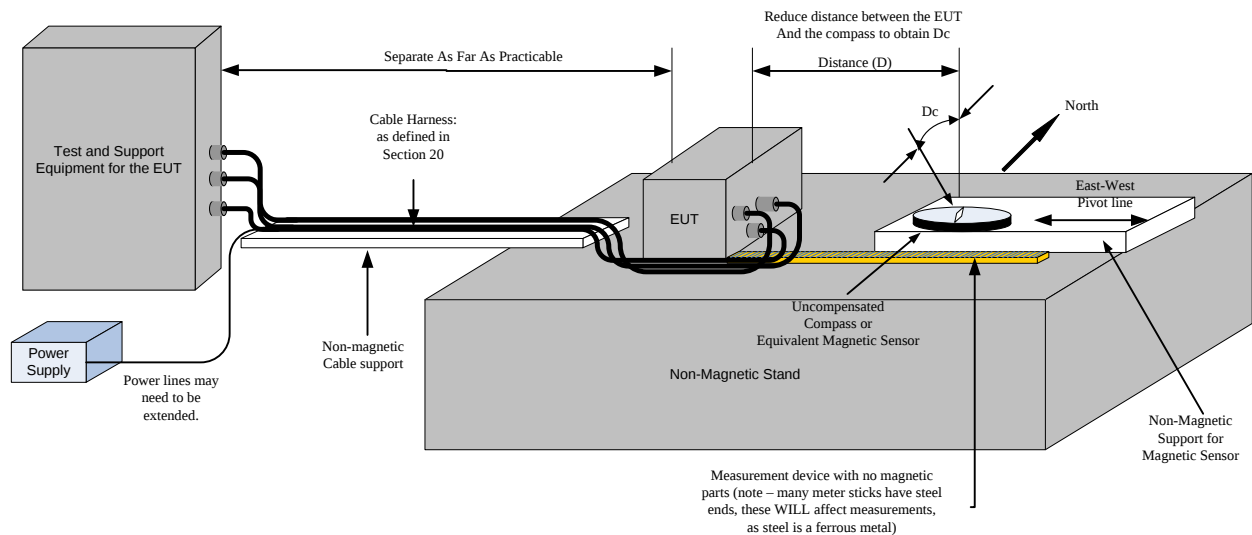


Figure 15-1 TEST INSTALLATION AND PROCEDURE

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 16

Power Input

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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16 Power Input

16.1 Purpose of the Test

This section defines test conditions and procedures for ac and dc electrical power applied to the terminals of the equipment under test. It covers the following electrical power supplies:

- 14 V dc, 28 V dc and 270 V dc
- 115 Vrms ac and 230 Vrms ac at either a nominal 400 Hz frequency or over a variable frequency range which includes 400 Hz.

Equipment categories and frequency classes, test conditions and procedures for equipment using other electrical power supplies must be defined in applicable equipment performance standards.

16.2 Equipment Categories and Test Designations

The marking of equipment consists of:

First a category reference:

- For ac equipment: A(CF), A(NF) or A(WF)
- For dc equipment: A, B, D or Z

Next, for all ac equipment, the category reference is followed by additional test designation letters to indicate if the equipment has to be subjected or not to the following tests:

- ac harmonic tests (letter H) or not (letter X),
- ac current modulation tests (letter L) or alternate test (letter Z)
- ac power factor tests (letter P) or alternate test (letter Z),
- ac inrush tests (letter I) or alternate test (letter Z) or not (letter X)

Next, for all dc equipment, the category reference is followed by an additional test designation letters to indicate if the equipment has to be subjected or not to the following tests:

- dc current ripple tests (letter R) or not (letter X),
- dc inrush current tests (letter I) or alternate test (letter Z) or not (letter X).

AC only equipment test designations (such as the letter H) are not to be marked after dc equipment categories (such as A, B, D or Z). DC only equipment test designations (such as the letter R) are not to be marked after ac equipment categories (such as A(CF), A(NF) or A(WF)).

Should the unit accept both ac and dc power, the marking should first list the ac equipment category followed by all of the ac test designations then list the dc equipment category, followed by all of the dc test designations.

Categories A(CF), A(NF), A(WF) and A

Equipment intended for use on aircraft electrical systems where the primary power is from a constant or variable frequency ac system and where the dc system is supplied from transformer-rectifier units, is identified as:

- for ac equipment: Category A(CF), A(NF) or A(WF),
- for dc equipment: Category A.

A(CF) designates ac equipment intended for use on aircraft electrical systems where the primary power is from constant frequency (400 Hz) ac system.

Note: *A(CF) designates the same equipment as the ac ones designated by Category A in DO-160 / ED14 issues A to D.*

A(NF) designates ac equipment intended for use on aircraft electrical systems where the primary power is from narrow variable frequency (360 to 650 Hz) ac system.

A(WF) designates ac equipment intended for use on aircraft electrical systems where the primary power is from wide variable frequency (360 to 800 Hz) ac system.

"A" designates 28 V dc equipment intended for use on aircraft electrical systems where the dc is generated from primary power supplied from either a constant or variable frequency ac system. Category A dc equipment may have a battery floating on the dc bus.

Category B

14 V or 28 V dc equipment intended for use on aircraft electrical systems supplied by engine-driven alternator/rectifiers, or dc generators where a battery of significant capacity is floating on the dc bus at all times, is identified as Category B.

Category D

270 V dc equipment intended for use on aircraft electrical systems where the dc is generated from primary power supplied from either a constant or variable frequency ac system, is identified as Category D

Category Z

28 V dc equipment that may be used on all other types of aircraft electrical systems applicable to these standards is identified as Category Z. Category Z shall be acceptable for use in lieu of Category A or Category B. Examples of this category are dc systems supplied from variable speed generators where:

- a. The dc supply does not have a battery floating on the dc bus, or
- b. The control or protective equipment may disconnect the battery from the dc bus, or
- c. The battery capacity is small compared with the capacity of the dc generators.

AC Distortion Tests: Designation H

This test designation relates to ac equipment with an individual maximum power consumption greater than 35 VA or installations where the combined power consumption of multiple units (of the same equipment type) is greater than 150 VA. For such equipment, the current distortion tests of section 16.7.1 have to be performed if required by the equipment performance standards.

AC Current Modulation Control Tests: Designation L

This test designation relates to ac equipment where the current ripple (or current modulation) drawn from the EUT is controlled. AC powered equipment that meets the requirements of this test designation is to be marked with test designation L. Equipment that does not meet the requirements of designation L is to still be tested (report levels only) and is marked with test designation Z (other test criterion.)

AC Power Factor Tests: Designation P

This test designation relates to ac equipment where the power factor of the ac power drawn by the EUT is controlled. AC powered equipment that meets the requirements of this test designation is to be marked with test designation P. Equipment that does not meet the requirements of designation P is to still be tested (report levels only) and is marked with test designation Z (other test criterion.)

DC current ripple tests: Designation R

This test designation relates to dc powered equipment with an individual maximum power consumption greater than 400 W for 28V or 35 W for 270V or installations where the combined power consumption of multiple units (of the same equipment type) is greater than 400 W for 28V or 150 W for 270V. For such equipment, the DC current ripple tests of section 16.7.7 have to be performed if required by the equipment performance standards.

AC or DC Inrush Current tests: Designation I

This test designation is assigned to ac or dc equipment that meets the inrush current requirements specified for designation I. For such equipment, the inrush current tests of section 16.7.5 have to be performed if required by the equipment performance standards.

Standard Test Tolerances:

Unless otherwise specified in the controlling equipment specification or in the DO-160 test procedure:

- For nominal voltages greater than or equal to 100V ac or dc, all input power voltages shall be held to the higher of +/- 1.0% of the test voltage or +/- 1.0% of the nominal operating voltage, (i.e. 0 V ac on a 115V system is 0 V +/- 1.15V ac.)
- For nominal voltages less than 100V ac or dc, all input power voltages shall be held to the higher of +/- 2.0% of the test voltage or +/- 2.0% of the nominal operating voltage, (i.e. 0 V dc on a 28 V dc system is 0 V +/- 0.56 V dc.)
- All time durations shall to be held to within +/- 10% of the specified amount
- All rise and fall times shall be less than 1.5 msec between the 10% and 90% points of the actual voltage transition.
- All frequencies shall be held to within +/- 1.0% of the specified value.

Note: *These tolerances are for the purpose of applying standard test procedures to the equipment under test and do not reflect the actual tolerances of the aircraft power source.*

Manual Reset:

Manual Reset is the act of cycling all power to the EUT from on to off back to on to clear an EUT fault condition or an EUT latch up. Entering data into the EUT after a test, such as a power interrupt, is not considered to be a Manual Reset unless otherwise specified in applicable equipment performance standards.

16.3 Emergency Electrical System Operation

Emergency electrical system operation is defined as the condition of the electrical system during flight when the primary electrical system becomes unable to supply sufficient or proper electrical power, thus requiring the use of an independent source(s) of emergency power which is limited in power output capabilities.

16.4 Standard Electrical Power Input Parameters (ac)

Certain electrical parameters are considered standard, i.e., not varying from nominal limits throughout the requirements of this section. All tests shall be conducted with the following standard parameters:

CAUTION: All mentioned voltage values are for 115 Vrms ac equipment.
Multiply them by 2 for 230 Vrms ac equipment.

a. Phase Sequence

The voltage of the individual phases of a three phase supply are mutually displaced from each other by 120 electrical degrees; they are designated A, B, and C, and reach their respective peak values in that sequence.

b. Phase Displacement

This is the relative displacement between the zero voltage points on the waveforms of the three phases. The phase displacement will be within the following limits:

- A(CF) and A(NF) category equipment: 120 ± 4 electrical degrees
- A(WF) category equipment: 120 ± 6 electrical degrees

c. Phase Voltage Unbalance

c.1. A(CF) and A(NF) Category Equipment

For normal electrical system operation, the maximum spread in phase voltages will not exceed 6 volts root-mean-square (rms) between the phase with the highest voltage and the phase with the lowest voltage for all aircraft operations. This spread will not exceed 8 volts rms when the source of power is the emergency power system.

c.2. A(WF) Category Equipment

For normal electrical system operation, the maximum spread in phase voltages will not exceed 8 volts root-mean-square (rms) between the phase with the highest voltage and the phase with the lowest voltage for all aircraft operations. This spread will not exceed 10 volts rms when the source of power is the emergency power system.

d. Voltage waveform crest factor and harmonic content

The voltage waveform will have a crest factor 1.41 ± 0.15 and an harmonic content as specified in the table below.

Equipment category	Maximum voltage total harmonic distortion (*)	Maximum voltage individual harmonic content (*)
A(CF) and A(NF)	8 %	6 %
A(WF)	10 %	8 %

(*) For related definition, refer to section 16.5.1.8.1.

e. Voltage waveform dc content

For normal electrical system operation, the voltage waveform dc content will be within the following limits: 0 ± 0.20 V dc

f. Requirement

Compliance with subsequent requirements in this section infers compliance under these standard conditions.

16.5 Electrical Power Input Parameter Limits (ac)

The following defines quantitatively those parameters of electrical power input that are variable and the related test conditions where applicable, and are divided into those associated with NORMAL and ABNORMAL electrical system operation.

Testing to A(WF) allows use of A(WF), A(NF) and A(CF) input power.

Testing to A(NF) allows use of A(NF) and A(CF) input power.

Testing to A(CF) allows use of A(CF) input power.

Notes:

1. *The power source used should be able to supply the maximum current required by the EUT.*
2. *In the case where multiple power inputs are supplied by the same aircraft bus, all connections for these inputs shall be tested simultaneously.*

16.5.1 Normal Operating Conditions (ac)

The following conditions and tests are applicable to Category A(CF), A(NF) and A(WF) equipment.

CAUTION: All mentioned voltage values are for 115 Vrms ac equipment.
Multiply them by 2 for 230 Vrms equipment.

16.5.1.1 Voltage and Frequency (ac)

a. Definition

EQUIPMENT CATEGORY		A(CF)	A(NF)	A(WF)
MAX	VOLTAGE (Vrms)	Highest phase	122	122
		Average of three phases	120.5	120.5
	FREQUENCY (Hz)	Normal	410	650
		Emergency	440	650
MIN	VOLTAGE (Vrms)	Lowest phase	100	100
		Average of three phases	101.5	101.5
	FREQUENCY (Hz)	Normal	390	360
		Emergency	360	360

Notes:

1. The above mentioned voltage values are at equipment terminals.
2. For ac networks:
 - Nominal voltage is 115 Vrms
 - Nominal frequency is 400 Hz (A(CF) category only)

b. Requirement for Single Phase Equipment

- (1) Operate the equipment at maximum duty cycle for at least 30 minutes for each test. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period. For A(CF), the test may be run at the emergency frequency levels to satisfy both normal and emergency operating conditions.

Frequency and voltage to be applied at equipment terminals:

TEST	VOLTAGE (Vrms)	FREQUENCY (Hz)		
		A(CF)	A(NF)	A(WF)
1	122	410	650	800
2	100	410	650	800
3	122	390	360	360
4	100	390	360	360

- (2) For A(CF) category equipment designated to operate under emergency electrical system conditions, operate it at maximum duty cycle for at least 30 minutes for each test. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period.

Frequency and voltages to be applied at A(CF) category equipment terminals:

TEST	VOLTAGE (Vrms)	FREQUENCY (Hz)
1	122	440
2	100	440
3	122	360
4	100	360

c. Requirement for Three Phase Equipment

c.1 Requirement for A(CF) and A(NF) Category Three Phase Equipment

- (1) Operate the equipment at maximum duty cycle for at least 30 minutes for each test with the primary power adjusted first for a phase balance, then for a phase unbalance. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period. For A(CF), the test may be run at the emergency voltage and frequency levels to satisfy both normal and emergency operating conditions. For A(NF), the test shall be run in the table below for tests 1 through 4. For A(NF), the test may be run at the emergency voltage and frequency tests 5 through 8 to satisfy both normal operating conditions 5 through 8 and emergency operating conditions.

Frequency and voltages to be applied at equipment terminals:

TEST	PHASE A/B/C VOLTAGE (Vrms)			FREQUENCY (Hz)	
	Phase A	Phase B	Phase C	A(CF)	A(NF)
1	120.5	120.5	120.5	410	650
2	101.5	101.5	101.5	410	650
3	120.5	120.5	120.5	390	360
4	101.5	101.5	101.5	390	360
5	122	122	116	410	650
6	100	100	106	410	650
7	122	122	116	390	360
8	100	100	106	390	360

- (2) For equipment designated to operate under emergency electrical system conditions, operate it at maximum duty cycle for at least 30 minutes for each test with the primary power adjusted first for a phase balance, then for a phase unbalance. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period.

Frequency and voltages to be applied at equipment terminals:

TEST	PHASE A/B/C VOLTAGE (Vrms)			FREQUENCY (Hz)	
	Phase A	Phase B	Phase C	A(CF)	A(NF)
1	120.5	120.5	120.5	440	N/A
2	101.5	101.5	101.5	440	N/A
3	120.5	120.5	120.5	360	N/A
4	101.5	101.5	101.5	360	N/A
5	122	122	114	440	650
6	100	100	108	440	650
7	122	122	114	360	360
8	100	100	108	360	360

c.2 Requirement for A(WF) Category Three Phase Equipment

- (1) Operate the equipment at maximum duty cycle for at least 30 minutes for each test with the primary power adjusted first for a phase balance, then for a phase unbalance. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period.

Frequency and voltages to be applied at equipment terminals:

TEST	PHASE A/B/C VOLTAGE (Vrms)			FREQUENCY (Hz)
	Phase A	Phase B	Phase C	
1	120.5	120.5	120.5	800
2	101.5	101.5	101.5	800
3	120.5	120.5	120.5	360
4	101.5	101.5	101.5	360
5	122	122	114	800
6	100	100	108	800
7	122	122	114	360
8	100	100	108	360

- (2) For equipment designated to operate under emergency electrical system conditions, operate it at maximum duty cycle for at least 30 minutes for each test with the primary power adjusted for a phase unbalance. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 30-minute test period.

Frequency and voltages to be applied at equipment terminals:

TEST	PHASE A/B/C VOLTAGE (Vrms)			FREQUENCY (Hz)
	Phase A	Phase B	Phase C	
1	122	122	112	800
2	100	100	110	800
3	122	122	112	360
4	100	100	110	360

16.5.1.2 Voltage Modulation (ac)

a. Definition

Voltage modulation is the cyclic variation, random variation, or both, about the mean level of the ac peak voltage that may be encountered during steady state electrical system operation caused by voltage regulation variations and speed variations. For 115V ac systems, the voltage modulation will be 5.0 volts maximum peak-to-valley difference between the minimum and the maximum voltage reached on the modulation envelope or higher as indicated in the equipment specification. For 230V ac systems the voltage modulation will be twice that of 115V ac systems.

The frequency components of the 115V ac voltage modulation envelope waveform will not exceed the limits of Figure 16-1.

b. Requirement

The equipment, when subjected to this condition, shall operate within the applicable equipment performance standards. Any test requirement, if applicable, will be specified in the individual equipment performance standard. This test shall be performed with nominal voltage applied to the EUT and with a frequency of :

- 400 Hz for A(CF) category equipment
- 360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.

After adjusting the voltage modulation to match the minimum test levels listed in Figure 16-1, dwell for the longer of a minimum of 120 seconds at each frequency step or for the time indicated in the equipment specification. The frequency step size shall be a minimum of 4 logarithmically spaced steps per decade with additional test frequencies at each of the inflection points.

$$f_{n+1} = f_n * 10^{(1/4)}$$

where,

- | | |
|----|------------------------------------|
| fn | is a test frequency and n=1 to 4, |
| f1 | is the start frequency, and |
| f4 | is the end frequency in one decade |

16.5.1.3 Frequency Modulation (ac)

a. Definition

Frequency modulation is the cyclic or random variation, or both, of instantaneous frequency about a mean frequency during steady-state electrical system operation. The frequency modulation is normally within narrow frequency limits and occurs as a result of speed variations in a generator coupling and/or drive speed regulation. The variations of primary system frequency due to frequency modulation during will be within a band about the mean frequency defined by Figure 16-2.

b. Requirement

The equipment, when subjected to this condition, shall operate within the applicable equipment performance standards. This test shall be performed with nominal voltage applied to the EUT and with a mean frequency of :

- 400 Hz for A(CF) category equipment
- 360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.

After adjusting the width of frequency deviation to match the minimum test levels listed in Figure 16-2 at each repetition rate test point, dwell the longer of 5 repetition rate cycles, 30 seconds or for a time indicated in the equipment specification.

The minimum set of test points shall be per the table in Figure 16-2.

If the frequency deviation is applied as discrete frequency steps instead of a sinusoidal or a triangular frequency deviation, the repetition rate dwell times shall have equal durations within +/- 10% and the maximum frequency deviation step size shall be less than or equal to 2.0 Hz. For peak to peak ac frequency modulations less than or equal to 2.0 Hz, square wave frequency deviation is acceptable.

16.5.1.4 Momentary Power Interruptions (ac)

a. Definition

Transfer of power sources can result in power interruptions for periods up to 200 ms.

For equipment that has more than one power source, consult applicable performance standards for the states of the remaining power inputs during the testing of power interrupts on any given power input. Multiple primary power input connections that are intended to be tied in parallel external to the EUT in the installation are considered as the same power source.

b. Requirement for All ac Equipment

Equipment is sensitive to momentary power interruptions that can cause aberrations in performance. Such transient power interruptions may be of any function of V-transient and T-transient where V_t may have any value between V-steady state and zero, and T_t may be any value from 0 to 200 milliseconds. Since there are a multitude of such combinations, this test procedure selects discrete values that are considered effective for determining equipment performance.

Test Procedures

The equipment shall be fully operational.
Nominal voltage shall be applied prior to each test condition.

Concerning frequency:

- A(CF) category equipment: nominal frequency shall be applied prior to each test condition.
- A(NF) and A(WF) category equipment:
First, all tests will be performed with: 360 Hz +5/-0 Hz.
Then, all tests will be rerun with:
 - A(NF) category equipment: 650 Hz +0/-5 Hz
 - A(WF) category equipment: 800 Hz +0/-5 Hz.

Data shall have been entered, either manually or automatically, and all related displays functioning prior to each test condition.

For each representative operating mode of the equipment, or as specified in the applicable performance standards, apply each of the test conditions of Table 16-1 at least twice. If the difference between maximum and minimum steady state current is less than 25% of the maximum steady state current, only the maximum steady state current operating mode needs to be tested.

The second successive test application is to be applied after the system has fully stabilized. Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test. Manual reset is **not** permitted unless otherwise specified by the individual equipment specifications.

After exposure to all test conditions, for A(CF) equipment only, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. For A(NF) and A(CF) equipment, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS after exposure to both 16.4.1.4 b and 16.4.1.4 c.

Note: Any requirement for performance of the equipment during application of test will be specified in the equipment performance standards.

c. Additional Requirement (A(NF) and A(WF) Category Equipment Only)

The equipment shall be fully operational.
Nominal voltage shall be applied prior to each test condition.

For each representative operating mode of the equipment, or as specified in the applicable performance standards, apply each of the test conditions of Table 16-2 at least twice. If the difference between maximum and minimum steady state current is less than 25% of the maximum steady state current, only the maximum steady state current operating mode needs to be tested.

The second successive test application is to be applied after the system has fully stabilized. Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test. Manual reset is **not** permitted unless otherwise specified by the individual equipment specifications.

After exposure to all test conditions, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: Any requirement for performance of the equipment during application of test will be specified in the equipment performance standards.

16.5.1.5 Normal Transients (ac)

16.5.1.5.1 Normal Surge Voltage (ac)

a. Definition

A normal surge is a variation from the controlled steady-state level, resulting from the inherent regulation of the electrical power supply system in response to disturbances imposed by normal system operations, such as load switching and remedial action by the regulator.

b. Requirement

- (1) Operate the equipment for five minutes with a voltage of 115 Vrms at equipment terminals. Then cycle the voltage three times as indicated below:

Increase the voltage to:

- A(CF) and A(NF) category equipment: 160 -0/+6 Vrms for 30 ms.
- A(WF) category equipment: 170 -0/+7 Vrms for 30 ms.
- Return the voltage to 115 Vrms +/-5 Vrms for five seconds.
- Decrease the voltage to 70 Vrms -3/+0 Vrms for 30 ms.
- Return the voltage to 115 Vrms +/-5 Vrms for five seconds.

The required surge voltages as measured at the input terminals of the EUT shall be achieved regardless of the required surge current.

- (2) The supply frequency shall be as follows:

- A(CF) category equipment: 400 Hz $\pm$ 5 Hz.
- A(NF) category equipment: run test first with 360 Hz +5/-0 Hz,
then rerun test with 650 Hz +0/-5 Hz.
- A(WF) category equipment: run test first with 360 Hz +5/-0 Hz,
then rerun test with 800 Hz +0/-5 Hz

The voltage surges should be applied and monitored in a manner similar to that in Figure 16-3.

- (3) During the normal electric system surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: Unless so stated in the equipment performance standard, equipment may have degraded performance during the surge and must meet the specified performance when returned to nominal voltage and frequency.

- (4) Following application of the voltage surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: If the equipment performance standard requires that performance be met during the abnormal surge voltage test of subparagraph 16.5.2.3.1

and momentary undervoltage test of subparagraph 16.5.2.2, it is not necessary to run the above test.

16.5.1.5.2 Normal Frequency Transients (All ac Equipment)

a. Definition

A normal transient is a momentary variation from the controlled steady-state level, resulting from the inherent regulation of the electrical power supply system in response to disturbances imposed by normal system operations, such as engine speed changes and remedial action by the regulator. This test is performed on variable frequency equipment to insure compatibility with constant frequency equipment.

b. Requirement

- (1) Operate the equipment for five minutes with a voltage of 115 Vrms at equipment terminals and a frequency of 400 Hz.

Then cycle the frequency three times as indicated below:

- Increase the frequency to 440 Hz $\pm$ 5 Hz for 150 ms.
- Then lower the frequency to 420 Hz $\pm$ 5 Hz for 1.5 second.
- Return the frequency to 400 Hz $\pm$ 5 Hz for five seconds.
- Decrease the frequency to 350 Hz $\pm$ 5 Hz for 150 ms.
- Then increase the frequency to 380 Hz $\pm$ 5 Hz for 1.5 second.
- Return the frequency to 400 Hz $\pm$ 5 Hz for five seconds.

Transitions between frequency test points shall occur in less than 1 ms.

- (2) During the normal frequency transients, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: *Unless so stated in the equipment performance standard, equipment may have degraded performance during the transients and must meet the specified performance when returned to nominal voltage and frequency.*

- (3) Following application of the frequency transients, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: *If the equipment performance standard requires that performance be met during the abnormal frequency transients test of subparagraph 16.5.2.3.2, it is not necessary to run the above test.*

16.5.1.6 Normal Frequency Variations (A(NF) and A(WF) Category Equipment Only)

a. Definition:

Frequency variations up to 200 Hz/sec, unless otherwise specified in the applicable equipment performance standards, can occur in normal operating conditions as a result of quick engine speed changes more particularly during aircraft take-off and engine shutdown sequences.

b. Requirement:

- (1) Operate the equipment for five minutes with a voltage of 115 Vrms at equipment terminals and a frequency of 360 Hz +5/-0 Hz.

Then, cycle the frequency three times as indicated below:

Increase the frequency to:

- A(NF) category equipment: 650 Hz +0/-5 Hz
- A(WF) category equipment: 800 Hz +0/-5 Hz

with a constant frequency rate of change of 100 Hz/s, then return the frequency to 360 Hz +5/-0 Hz with the frequency rate of change at 200 Hz/s and maintain the frequency at 360 Hz +5/-0 Hz for five seconds.

- (2) During the normal frequency variations, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS

Note: *Unless so stated in the applicable equipment performance standards, equipment performance shall not be degraded during normal frequency variations.*

16.5.1.7 Voltage DC Content (ac)

a. Definition:

A voltage dc content up to ± 0.20 volt may be encountered during normal steady state electrical system operation. This dc voltage is the same for both 115V and 230 V ac systems.

b. Requirement:

Operate the equipment at maximum duty cycle with a voltage of 115 Vrms at its terminals and a frequency as specified in the note below. Apply to each of the primary input leads a voltage dc offset of -0.200 +0/-0.040 V dc.

The equipment shall operate in these conditions for at least 30 minutes.

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the 30-minute test period.

If the equipment is a three-phase unit, test each phase individually and then all phases simultaneously.

Repeat, with a voltage dc offset of +0.200 +0.040/-0 V dc.

The voltage dc offset may be produced as shown in Figure 16-9 for single-phase equipment and Figure 16-10 for three-phase equipment.

Note: These tests shall be performed with a frequency of:

- 400 Hz for A(CF) category equipment
- 360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.

16.5.1.8 Voltage Distortion (ac)

Current draw from non-linear ac loads will cause distortion in the ac voltage waveform under normal conditions (for detailed definitions, refer to paragraph 16.5.1.8.1). All ac equipment is expected to operate correctly with this distortion present.

16.5.1.8.1 Definitions

16.5.1.8.1.1 Total Harmonic Distortion

The total harmonic distortion of the ac waveform is the ratio of the rms value of the harmonics to the rms value of the fundamental. The formula defining total harmonic distortion (THD) is provided below. The variable 'X' may represent voltage or current, and may be expressed as an rms value or a peak value.

$$THD_X = 100 \cdot \frac{\sqrt{\sum_{n=2}^{\infty} X_n^2}}{X_1}$$

X_1 = Fundamental value of current or voltage;

X_n = n^{th} harmonic value of current or voltage.

Note: The frequency of the n^{th} harmonic (F_n) is an integer multiple of the fundamental frequency F_1 : $F_n = n \cdot F_1$

16.5.1.8.1.2 Individual Harmonic Content

The individual harmonic content is the voltage or current, as applicable, at a given harmonic frequency, expressed as a percentage of the fundamental. The formula defining individual harmonic content (IHC_n) is provided below. The variable 'X' may represent voltage or current, and may be expressed as an rms value or a peak value. The fraction expresses the amount of distortion at the n^{th} harmonic.

$$IHC_n = 100 \cdot \frac{X_n}{X_1} \quad \text{where: } X_1 = \text{Fundamental value of current or voltage;}$$

X_n = n^{th} harmonic value of current or voltage.

16.5.1.8.2 Requirement

Operate the equipment at maximum duty cycle with minimum voltage (as per table in subparagraph 16.5.1.1 a.) at its terminals and a frequency as specified below. The voltage distortion may be produced via a full-wave rectifier bridge as shown in [Figure 16-8](#). The

level of voltage distortion can be controlled by varying the load on the rectifier(s), and insertion of source impedance in the line. Alternatively, input voltage to the EUT may be distorted by clipping the supply voltage. The equipment shall operate in these conditions for at least 30 minutes.

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the 30-minute test period.

This test shall be performed with a frequency of:

- 400 Hz for A(CF) category equipment
- 360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.

This test shall be performed with a voltage total distortion level (THD_v) as follows:

- 8 % +2/-0 % for category A(CF) and A(NF) equipment
- 10 % +2/-0 % for category A(WF) equipment

16.5.2 Abnormal Operating Conditions (ac)

The following conditions and tests are applicable to all ac equipment.

CAUTION: All mentioned voltage values are for 115 Vrms ac equipment.
Multiply them by 2 for 230 Vrms ac equipment.

16.5.2.1 Abnormal Voltage and Frequency Limits in Steady State (ac)

a. Definition

	EQUIPMENT CATEGORY		A(CF)	A(NF)	A(WF)
MAX	VOLTAGE (Vrms)	Highest phase	134	134	134
		Average of three phases	132.5	132.5	132.5
	FREQUENCY (Hz)		430	N/A	N/A
MIN	VOLTAGE (Vrms)	Lowest phase	97	97	97
		Average of three phases	98.5	98.5	98.5
	FREQUENCY (Hz)		370	N/A	N/A

Notes: (1) The above mentioned voltage values are at equipment terminals.

The following power supply frequency shall be applied for the requirements included in the paragraphs b. and c. hereafter:

- A(CF) category equipment: 400 Hz
- A(NF) category equipment: tests to be performed first with 360 Hz then with 650 Hz
- A(WF) category equipment: tests to be performed first with 360 Hz then with 800 Hz.

- (2) Any requirement for performance of the equipment during application of the abnormal voltage and/or abnormal frequency (refer to the paragraphs b. to e. below) will be specified in the equipment performance standard.

b. Requirement for Single Phase Equipment

Operate the equipment at maximum duty cycle for at least 5 minutes for each test with the voltage at equipment terminals adjusted as mentioned in the table below. At the end of each test and with the equipment still energized, adjust this voltage to 115 Vrms and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

TEST	VOLTAGE (Vrms)
1	134
2	97

c. Requirement for Three Phase Equipment

Operate the equipment at maximum duty cycle for at least 5 minutes for each test with the primary power adjusted first for a phase balance, then for a phase unbalance. At the end of each test and with the equipment still energized, adjust the average voltage at equipment terminals to 115 Vrms and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS

Voltages to be applied at equipment terminals:

TEST	EQUIPMENT CATEGORY	PHASE A/B/C VOLTAGE (Vrms)		
		Phase A	Phase B	Phase C
1	All	132.5	132.5	132.5
2	All	98.5	98.5	98.5
3	A(CF) and A(NF)	134	134	128
3	A(WF)	134	134	126
4	A(CF) and A(NF)	97	97	103
4	A(WF)	97	97	105

d. Additional Requirement for Single Phase Equipment (A(CF) Category Equipment Only)

Operate the equipment at maximum duty cycle for at least 5 minutes for each test. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 5-minute test period.

Frequency and voltage to be applied at equipment terminals:

TEST	VOLTAGE (Vrms)	FREQUENCY (Hz)
1	122	430
2	100	430
3	122	370
4	100	370

e. Additional Requirement for Three Phase Equipment (A(CF) Category Equipment Only)

Operate the equipment at maximum duty cycle for at least 5 minutes for each test with the primary power adjusted first for a phase balance, then for a phase unbalance. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during each 5-minute period.

Frequency and voltages to be applied at equipment terminals:

TEST	PHASE A/B/C VOLTAGE (Vrms)			FREQUENCY (Hz)
	Phase A	Phase B	Phase C	
1	120.5	120.5	120.5	430
2	101.5	101.5	101.5	430
3	120.5	120.5	120.5	370
4	101.5	101.5	101.5	370
5	122	122	116	430
6	100	100	106	430
7	122	122	116	370
8	100	100	106	370

16.5.2.2 Momentary Undervoltage Operation (ac)

a. Definition

Momentary voltages in the range from zero to 97 Vrms may occur for any duration up to seven seconds.

b. Requirement

The equipment, when exposed to this condition, shall operate within the applicable equipment performance standards when returned to its normal operating voltage range.

With the equipment operating with a voltage of 115 Vrms at its terminals and a frequency as specified in the note below, decrease the input ac voltage to 60 Vrms, or as otherwise specified in the equipment specification, for seven seconds. With the equipment still energized, adjust the input ac voltage to 115 Vrms and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Repeat with 10 Vrms instead of 60 Vrms.

Note: *These tests shall be performed with a frequency of:*

- 400 Hz for A(CF) category equipment
- 360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.

16.5.2.3 Abnormal transients (ac)

16.5.2.3.1 Abnormal Surge Voltage (ac)

a. Definition

An abnormal surge is a variation from the controlled steady-state level, resulting from the inherent regulation of the electrical power supply system and remedial action by the regulator, such as during fault clearance. The abnormal ac surge voltage characteristics shall be within the limits defined by Figure 16-5.

b. Requirement

With the equipment operating with a voltage of 115 Vrms at its terminals and a frequency specified in the note below, apply to the primary input lead(s), a voltage surge of 180 Vrms for 100 ms and then reduce the voltage to 148 Vrms for one second. The voltage change from one level to another shall be done within 1 ms. The voltage is not to return to nominal between the first and second surge voltage. The voltage surges should be applied and monitored in a manner similar to that in Figure 16-3.

The required surge voltages as measured at the input terminals of the EUT shall be achieved regardless of the required surge current.

For single phase equipment apply each surge three times at ten-second intervals.

For three phase equipment apply each surge one time at ten second intervals between tests per the table below:

TEST	PHASE A/B/C Surge Pattern		
	Phase A	Phase B	Phase C
1	Surge	No Surge	No Surge
2	No Surge	Surge	No Surge
3	No Surge	No Surge	Surge
4	Surge	Surge	Surge

Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test.

Following application of voltage surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: *These tests shall be performed with a frequency of:*

- 400 Hz for A(CF) category equipment
- 360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.

16.5.2.3.2 Abnormal Frequency Transients (ac)**a. Definition**

An abnormal frequency transient is a variation from the controlled steady-state level, resulting from the inherent regulation of the electrical power supply system and remedial action by the regulator in response to fault condition such as abnormal engine speed change. Tests 1 and 2 are performed on variable frequency equipment to insure compatibility with constant frequency equipment

b. Requirement**Test 1, All ac Equipment:**

Operate the equipment for five minutes with a voltage of 115 Vrms at equipment terminals and a frequency of 400 Hz. Then, perform the following tests.

The following sequence shall be repeated three times. Allow the equipment to fully stabilize between each test sequence.:

- Decrease the frequency to 350 Hz $\pm$ 5 Hz in less than 1 ms and operate the equipment for 5 seconds.
- Decrease the frequency to 320 Hz $\pm$ 5 Hz in less than 1 ms and operate the equipment for 200 ms.
- Decrease the voltage to 0 Vrms in less than 1 ms and maintain at 0 Vrms for 200 -0/+20 ms.
- Return the voltage to 115 Vrms and the frequency to 400 Hz in less than 1 ms and operate the equipment for 10 seconds.

Test 2, All ac Equipment:

Operate the equipment for five minutes with a voltage of 115 Vrms at equipment terminals and a frequency of 400 Hz. Then, perform the following tests.

The following sequence shall be repeated three times. Allow the equipment to fully stabilize between each test sequence.

Cycle the frequency three times as indicated below:

- Increase the frequency to 480 Hz $\pm$ 5 Hz for 200 ms.
- Decrease the frequency to 440 Hz $\pm$ 5 Hz in less than 1 ms and operate the equipment for 5 seconds.
- Decrease the voltage to 0 Vrms in less than 1 ms and maintain at 0 Vrms for 200 -0/+20 ms.
- Return the voltage to 115 Vrms and the frequency to 400 Hz in less than 1 ms and operate the equipment for 10 seconds.

Test 3 A(NF) and A(WF) ac Equipment Only:

Operate the equipment for five minutes with a voltage of 115 Vrms at equipment terminals and a frequency of 400 Hz. Then, perform the following tests.

The following sequence shall be repeated three times. Allow the equipment to

fully stabilize between each test sequence.

- In less than 1 ms, increase the frequency to:
 - A(NF) category equipment: 680 Hz $\pm$ 5 Hz for 200ms
 - A(WF) category equipment: 900 Hz $\pm$ 5 Hz for 200ms
- Decrease the voltage to 0 Vrms in less than 1 ms and maintain at 0V for 200 –0/+20 ms
- Return the voltage to 115 Vrms and the frequency to 400 Hz in less than 1 ms and operate the equipment for 10 seconds.

Following application of the above tests, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

16.5.2.3.3 Abnormal Frequency Variations (A(NF) and A(WF) Equipment Only)

a. Definition:

Frequency variations up to 400 Hz/sec (decreasing), and 120 Hz/sec (increasing), unless otherwise specified in the applicable equipment performance standards, can occur in abnormal operating conditions as a result of quick engine speed changes more particularly during engine runaway or failure mode scenarios.

b. Requirement:

- (1) Operate the equipment for five minutes with a voltage of 115 Vrms at equipment terminals and a frequency of 360 Hz +5/-0 Hz.

Then, cycle the frequency three times as indicated below:

Increase the frequency to:

- A(NF) category equipment: 650 Hz +0/-5 Hz
- A(WF) category equipment: 800 Hz +0/-5 Hz

with a constant frequency rate of change of 120 Hz/s, then return the frequency to 360 Hz +5/-0 Hz with the frequency rate of change at 400 Hz/s and maintain the frequency at 360 Hz +5/-0 Hz for five seconds.

- (2) After exposure, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS

Note: Any requirement for performance of the equipment during application of the test will be specified in the equipment performance standards.

16.5.2.4 Loss of Phase Input (Three Phase ac Input Only)

a. Definition:

All three phase ac loads are to be designed such that no damage or unsafe condition will occur during and following removal of one or more input phase connections.

b. Requirement:

The equipment shall be supplied by a source having a voltage of 115 Vrms and a frequency as follows:

- 400 Hz for A(CF) category equipment
 - 360 Hz for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.
- a. Operate the equipment for a period of 5 minutes with all three phases supplied. With all three phases supplied, remove phase X and continue to apply normal operating voltage to the remaining two phases for a period of 30 minutes minimum.
 - b. Starting with power disconnected from the EUT remove phase X and then apply normal operating voltage to the remaining two phases for a period of 30 minutes minimum.
 - c. Operate the equipment for a period of 5 minutes with all three phases supplied. With all three phases supplied, remove both phase Y and Z and continue to apply normal operating voltage to the remaining phase for a period of 30 minutes minimum.
 - d. Starting with power disconnected from the EUT remove phase Y and Z and then apply normal operating voltage to the remaining phase for a period of 30 minutes minimum.

The phases selected shall be justified by the following criteria and documented in the test report.

- Phase X is the phase that is most susceptible to damage from a loss of single phase.
- Phase Y and Z are the phases that are most susceptible to damage from the loss of two phases.

Unless otherwise specified in the applicable performance standards, the maximum allowed circuit breaker is allowed to be placed in series with the EUT.

After exposure, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Manual reset is permitted unless not allowed by the individual specification.

Note: *Any requirement for performance of the equipment during application of test will be specified in the equipment performance standards.*

16.6 Electrical Power Input Parameter Limits (dc)

The following defines quantitatively those parameters of electrical power input that are variable and the related test conditions where applicable, and are divided into those associated with NORMAL and ABNORMAL electrical system operation.

Unless otherwise specified in applicable equipment performance standards:

The chassis shall be at the same dc potential as earth ground during all equipment tests. All test limits listed in this test standard are with respect to a negative ground system.

The return lead (negative lead) for all 14V and 28 V dc equipment tests shall be at the same dc potential as the earth ground during all equipment tests.

270 V dc equipment may be used either as positive ground, negative ground or floating ground. Except as noted, all 270 V dc tests are to be performed with the 270V power source's negative lead at the same dc potential as earth ground during all equipment tests.

Notes:

1. *The power source used should be able to supply the maximum current required by the EUT.*
2. *In the case where multiple power inputs are supplied by the same aircraft bus, all connections for these inputs shall be tested simultaneously.*

16.6.1 Normal Operating Conditions (dc)

The following conditions and tests are applicable to Category A, Category B, Category D and Category Z equipment.

CAUTION: All mentioned 28V voltage values are to be divided by 2 for 14 V dc equipment.

16.6.1.1 Voltage (Average Value dc)

a. Definition:

Voltage at Equipment Terminals	28 V dc	270 V dc
Maximum	30.3 V	285 V
Minimum	22.0 V	235 V
Emergency Operation	18.0 V	235 V

Note: Nominal dc network voltage is with regards to:

Category A equipment: 28V
 Category B equipment: 28V or 14V
 Category Z equipment: 28V
 Category D equipment: 270V

b. Requirement

- (1) Operate the equipment at maximum duty cycle for at least 30 minutes with voltage at its terminals adjusted to the appropriate maximum voltage. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during this 30-minute period. The test may be run at the abnormal voltage levels to satisfy both normal and abnormal maximum operating conditions.
- (2) Operate the equipment for at least 1 minute with nominal voltage at its terminals, then adjust voltage at equipment terminals to the appropriate minimum voltage $\pm 1\%$ and operate the equipment at maximum duty cycle for at least 30 minutes. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during this 30-minute period. The test may be run at the abnormal voltage levels to satisfy both normal and abnormal minimum operating conditions. For category A, B and Z equipment, the test may be run at the emergency voltage levels to satisfy the normal, abnormal and emergency minimum operating conditions.
- (3) For equipment designated to operate under emergency electrical system conditions, operate the equipment for at least 1 minute with nominal voltage at its terminals, then adjust the voltage at the equipment terminals to the appropriate emergency minimum voltage $\pm 1\%$ and operate the equipment at maximum duty cycle for at least 30 minutes. DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during this 30-minute period.
- (4) For category D equipment only: With the power source's positive lead referenced to earth ground, operate the equipment at maximum duty cycle for at least 30 minutes with voltage at its terminals adjusted to the appropriate maximum voltage. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during this 30-minute period.

After determining compliance with applicable equipment performance standards, turn the 270V power source off, verify the voltage has dropped to a safe level and then return the 270V power source to have its negative lead referenced to earth ground

16.6.1.2 Ripple Voltage (dc)

a. Definition and ripple maximum level:

Ripple is the cyclic variation about the mean level of the dc voltage during steady state dc electrical system operation.

- In 28 V dc network, the cyclic peak-to-peak dc ripple voltage will be less than 4 volts if voltage at equipment terminals is above or equal to 22 V; if not, ripple voltage will be less than 2 V.
- In 270 V dc network, the cyclic peak-to-peak dc ripple voltage will be less than 16 volts

- b. Requirements related to ripple frequency components:

Refer to the paragraph 18.3.1 of subsection 18.3.

Note: Categories R, B, Z and Z defined in section 18 correspond respectively to categories A, B, D and Z as defined in section 16

16.6.1.3 Momentary Power Interruptions (dc)

- a. Definition

Transfer of power sources can result in power interruptions for any period up to 200 ms for Category A and 50 ms for Category B equipment, and 1.0 second for Category D and Z equipment.

For equipment that has more than one power source, consult applicable performance standards for the states of the remaining power inputs during the testing of power interrupts on any given power input. Multiple primary power input connections that are intended to be tied in parallel external to the EUT in the installation are considered as the same power source.

- b. Requirement for Equipment with Digital Circuits

This test is applicable only to equipment that incorporates digital circuitry and/or memory devices, including equipment with delay circuits.

This type of equipment is sensitive to momentary power interruptions that can cause aberrations in performance. Such transient power interruptions may be of any function of V-transient and T-transient where V_t may have any value between V-steady state and zero, and T_t may be any value from 0 to 1 second. Since there are a multitude of such combinations, this test procedure selects discrete values that are considered effective for determining equipment performance.

Test Procedures

The equipment shall be fully operational.
Nominal voltage shall be applied prior to each test condition.

Data shall have been entered, either manually or automatically, and all related displays functioning prior to each test condition.

For each representative operating mode of the equipment, or as specified in the applicable performance standards, apply each of the test conditions of Table 16-3 at least twice. If the difference between maximum and minimum steady state current is less than 25% of the maximum steady state current, only the maximum steady state current operating mode needs to be tested.

The second successive test application is to be applied after the system has fully stabilized. Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test.

After exposure, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Manual reset is **not** permitted

unless otherwise specified by the individual equipment specifications.

Note: Any requirement for performance of the equipment during application of test will be specified in the equipment performance standards.

c. Requirement for All Equipment

This test is applicable to all dc equipment.

Test Procedures

With the equipment operating at its design voltage(s), interrupt the power for a minimum of five times; each interrupt period shall last 50 ms whatever the category of equipment. Repeat this procedure with interrupt periods of 200 ms for Category A and Category D equipment, and 1 second for Category Z equipment.

Each successive test application is to be applied after the system has fully stabilized. Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test.

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Manual reset is **not** permitted unless otherwise specified by the individual equipment specifications.

Note: Any requirement for performance of the equipment during application of test will be specified in the equipment performance standards.

d. Double Interrupt Requirement for dc Equipment with Digital or Memory Devices

This test is applicable only to dc equipment that incorporates digital circuitry and/or memory devices, including equipment with electrical or mechanical delay devices.

This test relates to all dc equipment categories as they may be subjected to double switching phenomenon.

Test Procedures

The equipment shall be fully operational.
Nominal voltage shall be applied prior to each test condition.

Data shall have been entered, either manually or automatically, and all related displays functioning prior to each test condition.

For each representative operating mode of the equipment, or as specified in the applicable performance standards, apply each of the test conditions of Table 16-7 once with $T_2 = 10$ ms and again with $T_2 = 50$ ms. If the difference between maximum and minimum steady state current is less than 25% of the maximum steady state current, only the maximum steady state current operating mode needs to be tested.

Monitor the performance of the equipment (including any equipment/system normally operated in parallel) both during and subsequent to application of each test. After each test condition, verify equipment operation per manufacture's recommendations. The test conditions may be applied in any order. The next test

application is to be applied after the system has fully stabilized. Manual reset is **not** permitted unless otherwise specified by the individual equipment specifications

After exposure to all test conditions, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

***Note:** Any requirement for performance of the equipment during application of test will be specified in the equipment performance standards*

16.6.1.4 Normal Surge Voltage (dc)

a. Definition

A normal surge is a variation from the controlled steady-state level. It results from the inherent regulation of the electrical power supply system in response to disturbances that are imposed by normal system operations, such as load switching and remedial action by the regulator.

b. Requirement (Category A, B and Z equipment only)

- (1) Operate the equipment for five minutes with a voltage of 28 V dc at its terminals, then cycle the voltage three times as indicated below:

Increase the voltage to 47 V dc $-0/+2$ V dc for 5 ms then decrease the voltage to 40 V dc $-0/+2$ V dc for 30 ms for Category A and Category B equipment. Increase the voltage to 50 V dc $-0/+2$ V dc for 50 ms for Category Z equipment. Return the voltage to 28 V dc for five seconds. The rise time from one level to another shall be done within 1 ms, the fall time from one level to another shall be done within 5 ms. The voltage is not to return to nominal between the first and second surge voltage for Category A and Category B equipment..

Decrease the voltage to 17 V dc $-0.7/+0$ V dc for Category A and Category B equipment, and to 12 V dc $-0.7/+0$ V dc for Category Z equipment for 30 ms. Return the voltage to 28 V dc for five seconds. The voltage change from a level to another should be done within 1 ms.

The required surge voltages as measured at the input terminals of the EUT shall be achieved regardless of the required surge current.

- (2) The voltage surge should be applied and monitored in a manner similar to that in Figure 16-4.
- (3) During the normal electrical system surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

***Note:** Unless so stated in the individual equipment performance standard, equipment may have degraded performance during the surge and must meet the specified performance when returned to nominal voltage.*

- (4) Following application of the voltage surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: If the equipment performance standard requires that performance be met during the abnormal surge voltage test of subparagraph 16.6.2.4 and momentary undervoltage test of subparagraph 16.6.2.3, it is not necessary to run the above test.

c. Requirement for 270 V dc equipment (Category D equipment only)

- (1) Operate the equipment for five minutes with a voltage of 270 V dc V dc at its terminals, then cycle the voltage three times as indicated below:

Increase the voltage to 400 V dc -0/+16 V dc for 30 ms -0/+3ms.
Return the voltage to 270 V dc $\pm$ 11 V dc for five seconds minimum.
The rise time from one level to another shall be done within 1 ms, the fall time from one level to another shall be done within 5 ms.

Decrease the voltage to 160 V dc -7/+0 V dc for 30 ms -0/+3ms.
Return the voltage to 270 V dc $\pm$ 11 V dc for five seconds minimum.
The fall time from one level to another shall be done within 5 ms, the rise time from one level to another shall be done within 1 ms.

The required surge voltages as measured at the input terminals of the EUT shall be achieved regardless of the required surge current.

- (2) The voltage surge should be applied and monitored in a manner similar to that in Figure 16-4.
- (3) During the normal electrical system surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: Unless so stated in the individual equipment performance standard, equipment may have degraded performance during the surge and must meet the specified performance when returned to nominal voltage.

- (4) Following application of the voltage surges, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: If the equipment performance standard requires that performance be met during the abnormal surge voltage test of subparagraph 16.6.2.4 and momentary undervoltage test of subparagraph 16.6.2.3, it is not necessary to run the normal surge voltage test.

16.6.1.5 Engine Starting Under Voltage Operation (dc)

a. Definition

This requirement applies to Category Z and 28 volt Category B equipment. During engine starting, momentary voltages in the range from 10.0 to 20.5 V dc may occur for any duration up to 35 seconds or as indicated in the equipment specification.

b. Requirement

With the equipment energized at nominal rated voltage, decrease the input voltage to 10.0 V dc and increase 0.30 volts per second for 35 seconds, then return to rated voltage or as indicated in the equipment specification. During this period the equipment performance can fall to a level stipulated in the equipment specification. Return the voltage to its nominal value and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

16.6.1.6 Exposed Voltage Decay Time (dc, Category D Equipment Only)

a. Definition

Voltages on exposed external surfaces of the EUT are to be maintained at a safe level during normal operation. Voltages on all external surfaces of the EUT must decay to a safe level in a reasonable amount of time after power is removed from EUT.

b. Requirements

- (1) With the EUT installed in a manner representative of the installation in the aircraft, operate the equipment for at least one minute with nominal voltage at its terminals. Excluding female connector pins, all exposed voltages in this condition shall be less than 50V peak in magnitude with respect to the chassis and less than 50V peak with respect to each other.
- (2) Monitor all 270V hot and 270V return connection points on the EUT with 10 megohms +/- 20% < 30 pF probes with respect to chassis ground including both male and female connector pins. Operate the equipment for at least one minute with nominal voltage at its terminals then abruptly disconnect all 270V hot and all 270V return lines to the EUT.

The voltage from 270V hot to chassis, the voltage from 270V return to chassis and the voltage between 270V hot to 270V return shall decay to less than 50V peak in the times listed below:.

- a) 270V connection points on the EUT that are exposed by removing a connector from the EUT while the EUT is still mounted in the airframe are to be tested 1 +0/-0.1 second after removal of power.
- b) 270V connection points on the EUT that are exposed by removing the EUT from the airframe are to be tested 10 +0/-1.0 second after removal of power.
- (3) If the EUT can be placed in a non-operating mode with power applied to the EUT, repeat step (2) with the EUT in the power applied non-operating mode.

16.6.2 Abnormal Operating Conditions (dc)

The following conditions and tests are applicable to Category A, Category B, Category D and Category Z equipment.

CAUTION: All mentioned 28V voltage values are to be divided by 2 for 14 V dc equipment.

16.6.2.1 Voltage Steady State (dc)

a. Definition

Abnormal voltage limits that may be encountered are:

Voltage at Equipment Terminals	28 V dc	270 V dc
Maximum	32.2 V	320 V
Minimum	20.5 V	220 V

Note: Nominal dc network voltage is with regards to:

Category A equipment: 28V

Category B equipment: 28V or 14V

Category Z equipment: 28V

Category D equipment: 270V

b. Requirement

- (1) Operate the equipment for at least five minutes with voltage at its terminals adjusted to the appropriate maximum voltage. With the equipment operating, reduce this voltage to nominal voltage and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.
- (2) Operate the equipment for at least one minute with nominal voltage at its terminals, then adjust voltage at equipment terminals to the appropriate minimum voltage $\pm 0/-1\%$ and operate the equipment for at least five minutes. With the equipment still energized, increase voltage at its terminals to nominal voltage and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: Any requirement for performance of the equipment during application of the abnormal voltage will be specified in the equipment performance standard.

16.6.2.2 Low Voltage Conditions (dc, Category B Equipment Only)

a. Definition

Voltages in the range from zero to the appropriate minimum voltage may occur for any duration up to ten minutes.

b. Requirement

Operate the equipment for at least one minute with nominal voltage at its terminals then adjust the input power voltage(s) to the normal operating minimum voltage and operate the equipment for at least one minute. With the equipment still energized, decrease the input power voltage(s) linearly to zero over a minimum period of 10 minutes. With the equipment still connected, adjust the input power voltage(s) to the equipment's appropriate nominal voltage and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

If the linear decay to zero is applied in discrete steps, the step size shall be smaller than 0.25V and the minimum dwell time at each step shall be 600 seconds divided by the number of steps.

16.6.2.3 Momentary Undervoltage Operation (dc)

a. Definition

Voltages may momentarily vary below nominal for any duration up to seven seconds.

b. Requirement (Category A, B and Z equipment only)

The equipment, when exposed to this condition, shall operate within the applicable equipment performance standards when returned to normal operating voltage range.

With the equipment energized at nominal rated voltage, decrease the input dc voltage to 12.0 V +/- 0.24 V for seven seconds. With the equipment still energized, adjust the input dc voltage to nominal rated value and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

c. Requirement for 270 V dc equipment (Category D equipment only)

The equipment, when exposed to this condition, shall operate within the applicable equipment performance standards when returned to normal operating voltage range.

With the equipment operating with a voltage of 270 V dc at its terminals, decrease the input dc voltage to 140 +/- 2 V, or as otherwise specified in the equipment specification, for seven seconds minimum. With the equipment still energized, adjust the input dc voltage to 270 V and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Repeat test with 20.0 +/- 1 V instead of 140 V.

16.6.2.4 Abnormal Surge Voltage (dc)

a. Definition

An abnormal surge is a variation from the controlled steady-state level, resulting from the inherent regulation of the electrical power supply system and remedial action by the regulator, such as during fault clearance. The transient surge voltages that may be encountered are shown in Figure 16-6.

b. Category Z requirement

With the equipment operating at its appropriate nominal voltage, apply to the positive (dc) input lead voltage surges of 80 -0/+4 V dc for 100 ms and then reduce the voltage to 48 -0/+4 V dc for one second. The rise time from one level to another shall be done within 1 ms, the fall time from one level to another shall be done within 5 ms. The voltage is not to return to nominal between the first and second surge voltage.. The voltage surges should be applied and monitored in a manner similar to that in Figure 16-4. Apply each voltage surge three times at ten-second intervals. Following this test, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The required surge voltages as measured at the input terminals of the EUT shall be achieved regardless of the required surge current.

c. Category A requirement

With the equipment operating at its appropriate nominal voltage, apply to the positive (dc) input lead voltage surges of 46.3 -0/+2 V dc for 100 ms and then reduce the voltage to 37.8 -0/+2 V dc for one second, unless otherwise specified in the equipment specifications. The rise time from one level to another shall be done within 1 ms, the fall time from one level to another shall be done within 5 ms. The voltage is not to return to nominal between the first and second surge voltage.. The voltage surges should be applied and monitored in a manner similar to that in Figure 16-4. Apply each voltage surge three times at ten-second intervals. Following this test, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The required surge voltages as measured at the input terminals of the EUT shall be achieved regardless of the required surge current.

d. Category B requirement

With the equipment operating at its appropriate nominal voltage, apply to the positive (dc) input lead voltage surges of 60 -0/+3 V dc for 100 ms and then reduce the voltage to 40 -0/+2 V dc for one second, unless otherwise specified in the equipment specifications. The rise time from one level to another shall be done within 1 ms, the fall time from one level to another shall be done within 5 ms. The voltage is not to return to nominal between the first and second surge voltage. The voltage surges should be applied and monitored in a manner similar to that in Figure 16-4. Apply each voltage surge three times at ten-second intervals. Following this test, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The required surge voltages as measured at the input terminals of the EUT shall be achieved regardless of the required surge current.

e. Category D Requirement

With the equipment operating at its appropriate nominal voltage, apply to the positive (dc) input lead voltage surges of 425 -0/+17 V dc for 100 ms -0/+10 ms and 345 -0/+14 V dc for one second minimum. The rise time from one level to another shall be done within 1 ms, the fall time from one level to another shall be done within 5 ms. The voltage is not to return to nominal between the first and second surge voltage. The voltage surges should be applied and monitored in a manner similar to that in Figure 16-4. Apply each voltage surge three times at ten-second intervals. Following this test, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The required surge voltages as measured at the input terminals of the EUT shall be achieved regardless of the required surge current.

16.7 Load Equipment Influence on Aircraft Electrical Power System (ac and dc)

16.7.1 Current Harmonic Emissions from Loads (ac), Designation H

16.7.1.1 Definitions

The following requirements shall be met for ac powered equipment with test designation H (as defined in section 16.2). Equipment that does not test current harmonic emissions is to be marked with designation X.

Refer to section 16.5.1.8.1 for further definitions.

16.7.1.2 Current Distortion

Current distortion from ac powered equipment is tested with two input voltage conditions.

1. When supplied with a voltage waveform of low Total Harmonic Distortion (THD_V at the EUT input less than 1.25 % according to Test Condition 1, Verification Requirements, paragraph 16.7.1.3), the equipment shall not demand harmonic current components greater than 1.25 % above that already specified in Tables 16-4 and 16-5 for every 1 % of distortion in the corresponding individual voltage harmonic.

Notes:

- a. *If the EUT power is greater than 2 kVA, the THD_V may be greater than 1.25 % but shall not exceed 4 %.*
- b. *For example of calculation of the harmonic current component limits, refer to Table 16-6.*

2. When supplied with a distorted voltage waveform (Test Condition 2, Verification Requirements, paragraph 16.7.1.3), the equipment shall not demand harmonic currents greater than 1.25% above that already specified in Tables 16-4 and 16-5 for every 1% of distortion in the corresponding individual voltage harmonic.

Note: *For example of calculation of the harmonic current component limits, refer to Table 16-6.*

Commentary: Distorted voltage waveform requirements are required to ensure the EUT is stable when exposed to realistic power system conditions (Refer also to section 16.5.1.8).

16.7.1.3 Current Distortion Verification Requirements

CAUTION: All mentioned voltage values are for 115 Vrms equipment. Multiply them by 2 for 230 Vrms equipment.

The following data shall be supplied as part of the qualification test procedure to verify compliance with distortion requirements in the design requirements under all operating modes:

1. A description of the operating mode of equipment when the measurement was taken;
2. A description of the test setup, a copy of the test procedure, and a description of test equipment used and their settings;
3. Plot of current and voltage waveforms, with scaling information, for each phase of the equipment;
4. For A(CF) category equipment:
 - Tabulation of equipment input current and voltage harmonic components magnitude and phase (optional) for integral frequencies between 400 Hz and 16 kHz for each phase of the equipment;
 - Spectrum analysis plot of equipment input current (magnitude only) with a resolution of less than 20 Hz for each phase of the equipment.
5. For A(NF) category equipment:
 - Tabulation of equipment input current and voltage harmonic components magnitude and phase (optional) for integral frequencies of 360 Hz to 14.4 kHz and 650 Hz to 26 kHz for each phase of the equipment;
 - Spectrum analysis plot of equipment input current (magnitude only) with a resolution of less than 20 Hz for each phase of the equipment.
6. For A(WF) category equipment:
 - Tabulation of equipment input current and voltage harmonic components magnitude and phase (optional) for integral frequencies of 360 Hz to 14.4 kHz and 800 Hz to 32 kHz for each phase of the equipment;
 - Spectrum analysis plot of equipment input current (magnitude only) with a resolution of less than 20 Hz for each phase of the equipment.
7. True RMS of input current for each phase of the equipment; and
8. Total harmonic distortion of input current and voltage for each phase of the equipment.

These tests shall be performed for the equipment operating modes that draw maximum steady-state current and minimum steady-state current from the electrical power source used for these tests. If the difference between maximum and minimum steady state current is less than 25% of the maximum steady state current, only the maximum steady state current operating mode needs to be tested

Current harmonic measurements shall be performed in accordance with [Figure 16-7](#). Current measuring devices shall have an amplitude error of less than 3% and phase error (if reported) of less than 5 degrees for all frequencies up to 50 kHz.

Current harmonic components less than 10 mA, or less than 0.25 % of the fundamental, whichever is greater, shall be disregarded.

Spectrum analyzers or other harmonic analysis equipment shall be selected so that the resulting error in harmonic current measurement is less than 5% of the permissible limit, and the resulting frequency spectrum shall have a resolution of less than or equal to 20 Hz. Harmonic analysis equipment shall have capability of sufficiently high sampling rate, sufficiently long time window, appropriate window functions and anti-aliasing filters. As a guideline, the following test features should be considered:

- a. A sampling rate of 100 kHz or higher should be used.
- b. A time window of 0.05 seconds or longer should be used.
- c. An anti-aliasing filter with a corner frequency within 25 kHz to 50 kHz should be used.
- d. Either Rectangular, Hanning, Hamming, or Blackman-Harris windowing should be used.

If a spectrum analyzer or an EMI receiver is used to measure the harmonics, the following bandwidths, detection, and dwell times or minimum measurement times shall be used

Frequency Range	6 dB Bandwidth	Minimum Dwell Time per Harmonic (1)	Minimum Measurement Time (2)	Detection Setting (3)
Fundamental to 10 th Harmonic	10 Hz	1 s	0.1 s/Hz	Average
11 th Harmonic to 40 th Harmonic	100 Hz	1 s	0.1 s/Hz	Average

(1) For discrete frequency measurements

(2) For analog measurement receiver is used

(3) Analyzer to be put in max hold

The harmonics of the power line frequency up to the 40th harmonic shall be measured.

The intent of this test is to measure the power line harmonically related emissions; therefore, non-harmonically related emissions are exempt from this requirement. The amplitude and frequency measurement of the harmonics is a function of the accuracy of the fundamental power line frequency. Ensure that the fundamental is accurately measured and the harmonics are calculated based on this measurement.

Dwell and measurement times used during testing should be sufficient to measure any variations in harmonic amplitude. Longer dwell or measurement times are acceptable. Analog sweeps are to start at least ½ the bandwidth below the test frequency and end at least ½ the bandwidth above the test frequency.

Test conditions:

The equipment shall be tested under two conditions of input voltage distortion. In both cases, the equipment shall be supplied by a source having a voltage of 115 Vrms and a frequency as follows:

- A(CF) category equipment: 400 Hz $\pm$ 1%.
- A(NF) category equipment: 360, 400, 500, 600 and 650 $\pm$ 1 Hz
- A(WF) category equipment: 360, 400, 500, 600, 650, 700 and 800 $\pm$ 1 Hz.

The supply voltage and frequency shall remain constant within these limits while measurements are made.

Test Condition 1:

For the first test condition, the THD of the voltage (THD_V) at the input terminals of the equipment shall be less than 1.25% during the whole test.

Note: *If the EUT power is greater than 2 kVA, the output impedance of the source may not be sufficiently low to keep THD_V at the input of the EUT below 1.25%. In this case, THD_V may be greater than 1.25 % but shall not exceed 4%.*

Test Condition 2:

For the second test condition, the THD of the voltage (THD_V) at the input terminals of the equipment shall be:

- 8% +2/-0% for A(CF) and A(NF) category equipment
- 10% +2/-0% for A(WF) category equipment

during the whole test.

The voltage distortion may be produced via a full-wave rectifier bridge as shown in [Figure 16-8](#). The level of voltage distortion can be controlled by varying the load on the rectifier(s), and insertion of source impedance in the line. Alternatively, input voltage to the EUT may be distorted by clipping the supply voltage.

16.7.2 Allowable Phase Unbalance (Three Phase ac Input Only)**16.7.2.1 Definition**

The following requirements shall be met for all three phase ac equipment. The apparent (volt-amps), real (watts) and reactive (vars) power demands of any phase of a three-phase load shall not differ from similar power demands of any other phase, during any normal operating mode, by more than the limits of Figure 16-11.

16.7.2.2 Requirements

Operate the equipment with a balanced input voltage at nominal value and a frequency as follows:

- A(CF) category equipment: 400 Hz $\pm$ 1%.
- A(NF) category equipment: 400 Hz $\pm$ 1%, then 360 Hz $\pm$ 1%, then 650 Hz $\pm$ 1%.
- A(WF) category equipment: 400 Hz $\pm$ 1%, then 360 Hz $\pm$ 1%, then 800 Hz $\pm$ 1%.

The supply voltage and frequency shall remain constant within these limits while measurements are made.

Measure the load real power (W), apparent power (VA), and reactive power (VAR) for each of the three input phases at both a minimum and maximum power demand modes of operation. If there is less than a 25% difference between minimum and maximum power demand operating conditions, only one test at maximum power demand is required.

For loads with a power demand less than or equal to 1 kVA, the phase unbalance shall be less than 200VA, W or VAR. For loads with a power demand greater than 20kVA, the phase unbalance shall not differ by more than 800VA, W, or VAR. For loads between 1 kVA and 20 kVA, the phase balance shall remain within the limits of Figure 16-11.

16.7.3 DC Current Content in Steady-State Operation (All ac Equipment)

16.7.3.1 Definition

DC current content is the dc component of the ac line current drawn by the EUT.

16.7.3.2 Requirement

This requirement applies to all ac equipment that draws greater than 10 VA. Equipment that draws less than or equal to 10 VA is exempt from this requirement.

- (1) Operate the equipment in the mode that draws maximum steady-state current from the electrical power source used for this test, with a voltage of 115 Vrms, with a dc component of 0.00 +/- 0.10 V dc, at its terminals and a frequency as specified in the note below.

After stabilizing the equipment, measure the DC content of the equipment line current. The DC content shall not exceed the higher of 5 mA or 2 % of the maximum RMS value of the equipment current.

- (2) Operate the equipment in the mode that draws minimum steady-state current from the electrical power source used for this test, with a voltage of 115 Vrms, with a dc component 0.00 +/- 0.10 V dc, at its terminals and a frequency as specified in the note below.

After stabilizing the equipment, measure the DC content of the equipment line current. The DC content shall not exceed the higher of 5 mA or 2 % of the maximum RMS value of the equipment current.

If the difference between maximum and minimum steady state current is less than 25% of the maximum steady state current, only the maximum steady state current operating mode needs to be tested

Note: These tests shall be performed with a frequency of:

- 400 Hz for A(CF) category equipment
- 360 Hz, for variable frequency equipment then repeated with 650 Hz for A(NF) category equipment and 800 Hz for A(WF) category equipment.

16.7.4 Regenerated Energy (dc, Category D Equipment Only)

16.7.4.1 Definition

Regenerated energy is energy that flows from the load back to the power source. This energy typically comes from motor braking and from abrupt changes in load demand. This test measures regenerated energy by observing the voltage change across a 10 uF capacitor.

16.7.4.2 Requirement

With a voltage of 270 V dc at the EUT terminals, operate the equipment in the operating modes that draw maximum steady state current and minimum steady state current from the 270 V dc power source used for this test. If the difference between maximum and minimum steady state current is less than 25% of the maximum steady state current, only the maximum steady state current operating mode needs to be tested.

While operating, the equipment shall induce less than 8.0V zero to positive peak across the 10 uF +/- 10% capacitor shown in Figure 16-12. Monitor both sides of the diode in series with the 270V source during the test. The 270V is to have less than 1.0 V zero to positive peak ripple as measured at the anode of the series diodes during the test. The diode between the power source and the EUT shall have less than 1 µsec reverse recovery time.

CAUTION:

1. Potentially lethal voltages appear on both sides of the diodes and on the 10 uF capacitor.
2. EUTs that fail this test may cause the test set-up to explode. Install and use appropriate electrical and mechanical safe guards before running this test.
3. Before attempting to test an EUT for regenerated energy, verify with the EUT's manufacture that the EUT was designed to pass this test.

16.7.5 Inrush Current Requirements (ac and dc), Designation I.

16.7.5.1 Definition

The following requirements shall be met for equipment with designation I. Equipment that meets an alternate inrush test is to claim designation Z. Equipment that does not test inrush is to be marked with designation X.

16.7.5.2 Requirements

When the nominal input voltage is abruptly applied, the peak inrush current shall be less than:

- 9 times the maximum steady state load for the first 3.0 milliseconds,
- 4 times the maximum steady state load up to 500 msec, and
- 2 times the maximum steady state load up to 2 seconds and nominal thereafter.

Test Conditions:

The voltage rise time and fall time is to be less than 1/4 cycle for ac or less than 300 μ sec for dc.

For dc testing, the maximum steady state load is defined as the rated average current in the maximum steady state operating condition.

For ac testing, the maximum steady state load is defined as 1.41 times the rated RMS current in the maximum steady state operating condition.

Commentary: Maximum steady state load current draw generally occurs at low line input voltage to the EUT.

The unloaded test is to provide:

- 115V +/- 1 Vrms ac,
- 230V +/- 2 Vrms ac,
- 14.0V +/- 0.13 V dc,
- 28.0V +/- 0.25 V dc or
- 270V +/- 2.7 V dc.

At the maximum steady state load current draw with the power source with-in its unloaded voltage tolerance, add a resistor between the power source and each EUT power input hot lead to adjust the measured voltage drop between the power source and EUT to the following:

- 4.0V +/- 0.3 Vrms ac for 115V ac equipment
- 8.0V +/- 0.6 Vrms ac for 230V ac equipment
- 0.5V +/- 0.1 V dc for 14 V dc equipment.
- 1.0V +/- 0.1 V dc for 28 V dc equipment
- 9.0V +/- 0.9 V dc for 270 V dc equipment

This voltage drop from the wiring to the EUT is to be measure within 7 inches (0.18 m) of the regulation point of the power source and within 7 inches (0.18 m) the EUTs input terminal.

During the inrush test, with the appropriate series resistance to the EUT installed, the lab power source is to provide:

105.5 to 122 Vrms ac,
 211 to 244 Vrms ac,
 11.5 to 15.2 V dc,
 23.0 to 30.3 V dc or
 244 to 285 V dc

as measured at the lab power source's regulation point.

Test Condition 1:

With the equipment stationary and unpowered for a minimum of 5 minutes, apply nominal input voltage and verify that the equipment meets the requirements of this section.

Test Condition 2:

With the equipment stabilized and in its maximum input current operating mode, reduce the input voltage to less than 5% of nominal for a period of 200 +20/-0 msec and then apply nominal input voltage and verify that the equipment meets the requirements of this section.

Notes:

1. *This test shall be performed with a frequency of:*
 - *400 +5/-5 Hz for A(CF) category equipment*
 - *360 +5/-0 Hz for variable frequency equipment then repeated with 650 +0/-5 Hz for A(NF) category equipment and 800 +0/-5 Hz for A(WF) category equipment.*
2. *Abrupt application or removal of ac power occurring at the zero crossing of the ac voltage waveform is considered to meet the rise time requirements.*

16.7.6 Current Modulation in Steady-State Operation (ac), Designation L

16.7.6.1 Definition

The following requirements shall be met for ac powered equipment with test designation L (as defined in section 16.2) AC powered equipment that meets an alternate test condition is to be marked with designation Z.

Current Modulation is the cyclic variation, random variation, or both, about the mean level of the ac peak current that may occur during steady-state equipment operation. Any equipment which load current may modulate is potentially contributing to ac voltage modulation. Test designation L is intended for equipment with a maximum power consumption greater than 35 VA or a maximum total power consumption of all similar equipment type on airplane greater than 150 VA.

16.7.6.2 Requirement

Operate the equipment in the mode as determined by the equipment manufacturer that draws the maximum amount of input current modulation (i.e. the greatest variation of input peak to valley current as measured within a 500msec window.) from the electrical power source and with a voltage of 115 Vrms (see note 1 below) at its terminals and a frequency as specified in the note 2 below. If the equipment's input current modulation does not vary with operating mode, operate the equipment in the mode that draws maximum steady state current.

After the equipment has stabilized, at any time the value of the equipment line current modulation shall not exceed 0.28 peak to valley times the RMS value of the equipment maximum steady-state current for equipment of the same type < 1 kVA and 0.14 peak to valley times the RMS value for equipment maximum steady-state current ≥ 1 kVA. The load current is to be tested over at least three 500 msec long sweeps.

Notes:

1. *The AC source used to supply the EUT shall be such that the value of the voltage modulation is equal to or less than 420 mV peak to valley, whatever the modulation frequency is between 1 Hz and the higher of 200 Hz and one half the fundamental line frequency, when this AC source supplies a resistive load drawing a current equal to the EUT maximum steady-state current.*
2. *This test shall be performed with a frequency of:*
 - *400 +5/-5 Hz for A(CF) category equipment*
 - *360 +5/-0 Hz for variable frequency equipment then repeated with 650 +0/-5 Hz for A(NF) category equipment and 800 +0/-5 Hz for A(WF) category equipment.*
3. *The following load demand variations are exempt from this requirement:*
 - *Initial start-up*
 - *Transition between operating modes.*
 - *Responses to changes in input voltage and frequency.*
 - *Final shut-down.*
4. *This test is not intended to monitor current changes above the fundamental line frequency.*
5. *The current probe shall be dc coupled.*
6. *If the equipment under test supplies other loads, those downstream loads should be either connected during the test or simulated in a manner that represents similar modulation characteristics*

16.7.7 DC Current Ripple tests (dc), Designation R

16.7.7.1 Definition

Current ripple is the cyclic variation, random variation, or both, about the mean level of the dc current that may occur during steady-state equipment operation. Any equipment with load current modulation is potentially contributing to dc voltage ripple. The following requirements shall be met for dc powered equipment with test designation R

(as defined in section 16.2). Equipment that does not test DC current ripple is to be marked with designation X.

16.7.7.2 Requirement

Operate the equipment in the mode that draws minimum and maximum steady-state current from the electrical power source used for this test, with a voltage of 28 V dc for 28V networks and 270 V dc for 270V networks (see note 1 below). After the equipment has stabilized, the load current is to be tested over at least three 500 msec long sweeps. If the difference between maximum and minimum steady state current is less than 25% of the maximum steady state current, only the maximum steady state current operating mode needs to be tested.

28 V dc equipment

For equipment of the same type that draws a combined total power between 400 W and 1 kW, the peak to peak value of the individual equipment's line current ripple shall not exceed 0.140 times of the individual equipment's maximum load dc current draw.

For equipment of the same type that draws a combined total power greater than 1 kW, the peak to peak value of the individual equipment's line current ripple shall not exceed 0.070 times of the individual equipment's maximum load dc current draw.

270 V dc equipment

For equipment of the same type that draws a combined total power less than 1 kW, the peak to peak value of the individual equipment's line current ripple shall not exceed 0.280 times of the individual equipment's maximum load dc current draw.

For equipment of the same type that draws a combined total power between 1 kW and 10 kW, the peak to peak value of the individual equipment's line current ripple shall not exceed 0.140 times of the individual equipment's maximum load dc current draw.

For equipment of the same type that draws a combined total power greater than 10 kW, the peak to peak value of the individual equipment's line current ripple shall not exceed 0.070 times of the individual equipment's maximum load dc current draw.

Notes:

1. *The DC source used to supply the EUT shall have a voltage ripple that is equal to or less than 100 mV peak to peak for 28V networks and 1.00 V peak to peak for 270V networks, whatever the voltage ripple frequency is between 1 Hz and 200 Hz, when this DC source supplies a resistive load drawing a current equal to the EUT maximum steady-state current.*

2. *The following load demand variations are exempt from this requirement:*
 - *Initial start-up.*
 - *Transition between operating modes.*
 - *Responses to changes in input voltage.*
 - *Final shut-down.*
3. *This test is not intended to monitor current changes above 150 kHz (-3 dB point).*
4. *The current probe is to be dc coupled.*

16.7.8 Power Factor (All ac Equipment), Designation P

16.7.8.1 Definition

The following requirements shall be met for as powered equipment with test designation P (as defined in section 16.2). AC powered Equipment that does not meet the requirements of category P is to still be tested (report levels only) and is marked with test designation Z (other test criterion.)

Power factor is the ratio of the real power, P (Watts), to the apparent power, S (volt-amperes) as is shown below.

$$PF = \frac{P}{S}$$

$$P = 1/T \int_0^T V(t) * I(t) dt$$

$$S = V_{rms} * I_{rms}$$

This definition of power factor includes the effect of both displacement and distortion in the input current and voltage waveforms and is sometimes referred to as the true power factor.

16.7.8.2 Requirement

The EUT shall meet the power factor requirements when the power factor of the equipment is measured at the each of the following frequencies and two test voltages:

A(CF) to be 400 +/- 1 Hz

A(NF) to be 360 400 500 600 650 +/- 1 Hz

A(WF) to be 360 400 500 600 650 700 800 +/- 1 Hz

Test Voltage	Supply Voltage Single-Phase		Supply Voltage Three-Phase	
	115 Vrms	230V Vrms	115 Vrms	230 Vrms
1	100	200	101.5	203
2	122	244	120.5	241

- a) The steady-state full load power factor of motor loads shall be within the range given below:

- The leading PF shall be greater than 0.980
- The lagging PF shall be greater than 0.700 for frequencies above 500 Hz
- The lagging PF shall be greater than the following for frequencies between 360 Hz and 500 Hz

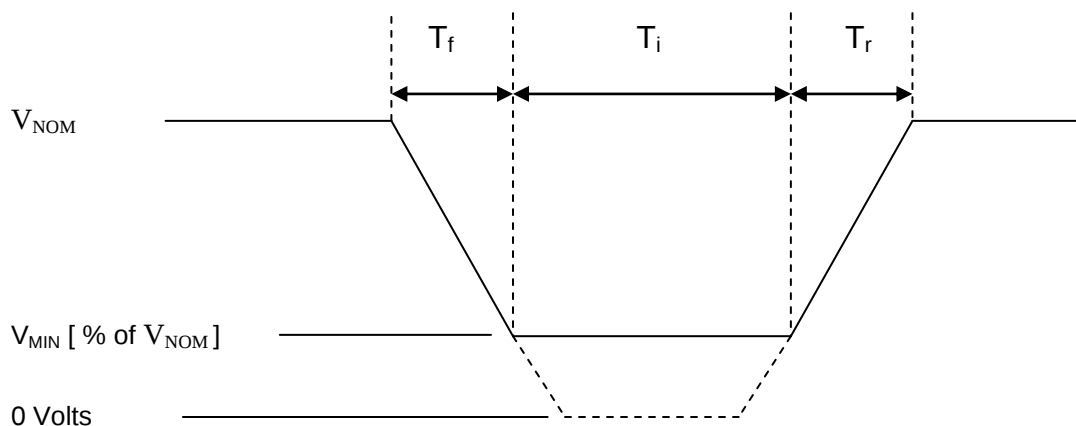
$$PF = 2.8571E-3 * Hz - 0.72857$$

- The lagging PF shall be greater than 0.300 for frequencies of 360Hz and below.

- b) For all other AC load equipment the power factor shall be equal or higher than the values listed below. For loads with a maximum total power consumption of all similar equipment on the airplane greater than 150VA, the steady-state full load power factor for each load shall be between 0.800 lagging and 0.968 leading.

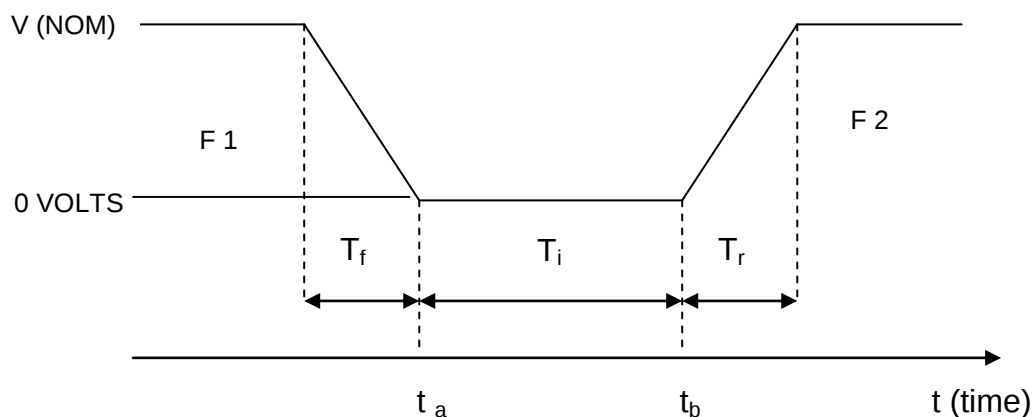
Load (KVA)	Power Factor - Leading	Power Factor - Lagging
≤ 0.02	0.200	0.200
0.03	0.355	0.321
0.04	0.464	0.406
0.06	0.619	0.527
0.08	0.728	0.613
0.10	0.813	0.679
0.15	0.968	0.800
Larger than 0.15	0.968	0.800

- The leading PF between 0.02 kVA and 0.15 kVA is given by
 $PF = 0.87765 * \log(kVA) + 1.69110$
- The lagging PF between 0.02 kVA and 0.15 kVA is given by
 $PF = 0.68567 * \log(kVA) + 1.36493$

Table 16-1 Test Conditions for All AC Equipment**Notes:**

- Definitions:**
 T_i Power interrupt time.
 T_f Time it would take for the applied voltage to decay from V_{NOM} to V_{MIN} volts.
 T_r Time it would take for the applied voltage to rise from V_{MIN} to V_{NOM} volts.
 V_{MIN} The minimum level (expressed as a percentage of V_{NOM}) to which the applied voltage is required to decay.
- Time (T_i , T_f , T_r) is to be the larger of 1 msec or $\pm 10\%$ with respect to the straight line voltage intercepts.

Test Condition	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
T_f (mS)	<1	10	17	18	19	20	20	10	25	50	43	48	50	18	20	13	5	<1	<1
T_i (mS)	2	0	8	32	56	80	180	0	0	0	33	53	150	13	15	27	20	50	200
T_r (mS)	<1	3	4	5	5	5	5	4	10	20	17	19	20	7	2	13	5	<1	<1
% V_{NOM} (V_{MIN})	0	50	15	10	5	0	0	80	50	0	15	5	0	65	60	35	0	0	0

Table 16-2 Additional Test Conditions for A (NF) and A(WF) Category Equipment**Notes:**

T_i = time at 0 volts

T_f = 20 ms

T_r = 5 ms

Time (T_i , T_f , T_r) is to be the larger of 1 msec or $\pm 10\%$ with respect to the straight line voltage intercepts.

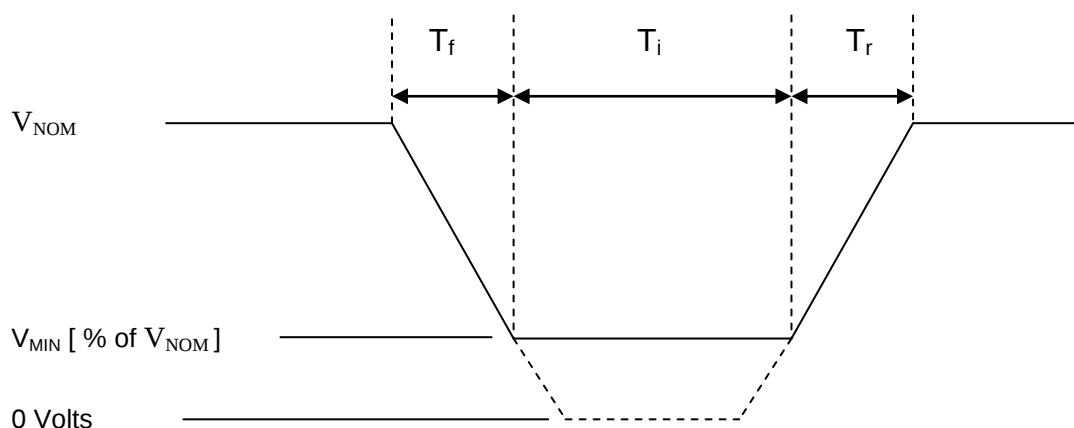
$F1$ = frequency of equipment voltage supply when $t \leq t_a$

$F2$ = frequency of equipment voltage supply when $t \geq t_b$

Test condition number	I	II	III	IV	V	VI
T_i (ms)	30	30	80	80	180	180
F1 (Hz)	360	F_{MAX}	360	F_{MAX}	360	F_{MAX}
F2 (Hz)	F_{MAX}	360	F_{MAX}	360	F_{MAX}	360

With $F_{MAX} = 650$ Hz for A(NF) category equipment

$F_{MAX} = 800$ Hz for A(WF) category equipment

Table 16-3 Test Conditions for DC Equipment with Digital Circuits**Notes:**

1. *Definitions:*
 - T_i Power interrupt time.
 - T_f Time it would take for the applied voltage to decay from V_{NOM} to V_{MIN} volts.
 - T_r Time it would take for the applied voltage to rise from V_{MIN} to V_{NOM} volts.
 - V_{MIN} The minimum level (expressed as a percentage of V_{NOM}) to which the applied voltage is required to decay.
2. Time (T_i , T_f , T_r) is to be the larger of 1 msec or ± 10 % with respect to the straight line voltage intercepts.

Applicable Category	A, B, D, Z				A, D, Z			D, Z.	A, B, D, Z.		A, D, Z				D, Z.	A, B, D, Z			
Test Condition	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
T _f (ms)	<1	10	17	18	19	20	20	20	10	25	50	43	48	50	50	18	20	13	5
T _i (ms)	<1	0	8	32	56	80	180	980	0	0	0	33	53	150	950	13	15	27	20
T _r (ms)	2	3	4	5	5	5	5	5	4	10	20	17	19	20	20	7	2	13	5
% V _{NOM} (V _{MIN})	0	50	15	10	5	0	0	0	80	50	0	15	5	0	0	65	60	35	0

Table 16-4 Current Harmonic Limits for Single-Phase Electrical Equipment

Harmonic Order	Limits
Odd Non Triplen Harmonics (h = 5, 7, 11, 13,..., 37)	$I_h = 0.3 I_1 / h$
Odd Triplen Harmonics (h = 3, 9, 15, 21, ..., 39)	$I_h = 0.15 I_1 / h$
Even Harmonics 2 and 4	$I_h = 0.01 I_1 / h$
Even Harmonics > 4 (h = 6, 8, 10, ..., 40)	$I_h = 0.0025 I_1$

Table 16-5 Current Harmonic Limits for Balanced Three-Phase Electrical Equipment

Harmonic Order	Limits
3 rd , 5 th , 7 th	$I_3 = I_5 = I_7 = 0.02 I_1$
Odd Triplen Harmonics (h = 9, 15, 21, ..., 39)	$I_h = 0.1 I_1 / h$
11 th	$I_{11} = 0.1 I_1$
13 th	$I_{13} = 0.08 I_1$
Odd Non Triplen Harmonics 17, 19	$I_{17} = I_{19} = 0.04 I_1$
Odd Non Triplen Harmonics 23, 25	$I_{23} = I_{25} = 0.03 I_1$
Odd Non Triplen Harmonics 29, 31, 35, 37	$I_h = 0.3 I_1 / h$
Even Harmonics 2 and 4	$I_h = 0.01 I_1 / h$
Even Harmonics > 4 (h = 6, 8, 10, ..., 40)	$I_h = 0.0025 I_1$

I_1 = maximum fundamental current of the equipment that is measured during the maximum steady-state power demand operating mode condition, at a single test frequency (*). This maximum current shall be used to calculate the current harmonic limits for all modes of operation, at that test frequency (*).

(*) For test frequency values, refer to section 16.7.1.3

h = order of harmonic.

I_h = maximum harmonic current of order h obtained for all normal steady state modes of operation.

Table 16-6 Test Designation H Test Condition 2 Compliance Table.

A Harmonic Order	B Current Harmonic Reqmt's (%)	C Harmonics in Voltage Waveform (%)	D= (B + C*1.25) Revised Current with 10mA limit Harmonic Reqmt's (%)	E Current Harmonics Emitted by Unit Under Test (%)	F Test Results
2	0.50	0.04	0.55	0.51	P
3	5.00	3.49	9.36	11.72	Fail
4	0.25	0.03	0.29 -> 0.40	0.35	P
5	6.00	2.99	9.73	7.53	P
6	0.25	0.12	0.40	0.15	P
7	4.29	1.67	6.37	13.20	Fail
8	0.25	0.02	0.28 -> 0.40	0.10	P
9	1.67	0.21	1.93	0.98	P
10	0.25	0.01	0.26 -> 0.40	0.05	P
11	2.73	0.72	3.63	3.00	P
12	0.25	0.03	0.29 -> 0.40	0.12	P
13	2.31	0.64	3.11	5.20	Fail
.					
40	0.25	0.0017	0.252 -> 0.40	0.0065	P

Column A identifies the harmonic order; for example, row 1, for A(CF) category equipment, is associated with the 800 Hz components of voltage and current (2 * 400 Hz). (For actual determination of load compliance with the harmonic requirements, the table should include data up to, and including, the 40th harmonic.)

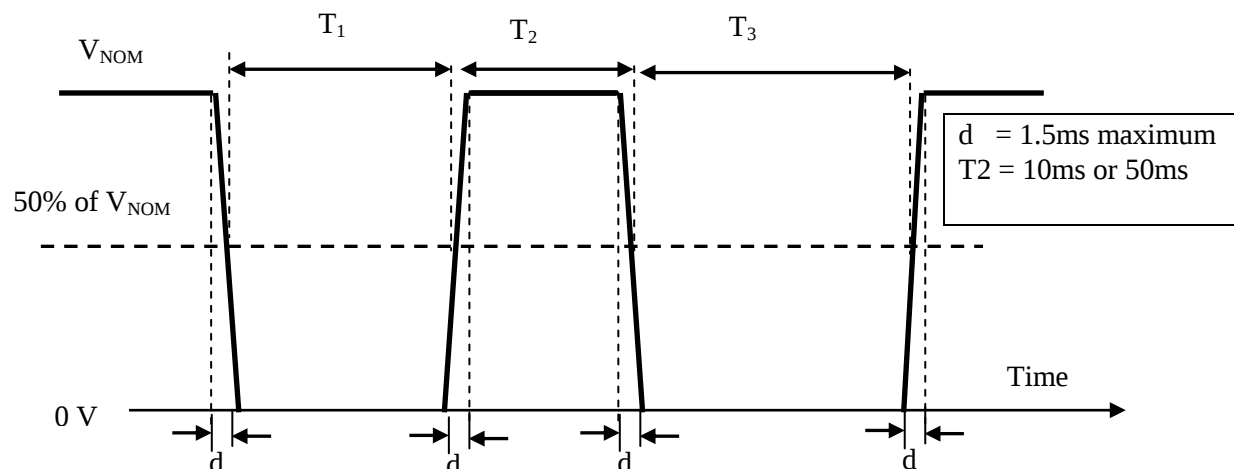
Column B lists the current harmonic requirements for a single phase load as determined from Table 16-4.

Column C is an example of what the voltage harmonic components may be for an applied voltage whose total harmonic distortion is greater than five percent (as specified in the test condition 2). It is stressed that column C are example numbers only, in practice this column would contain the actual harmonic components of the applied voltage.

Column D represents the allowed current harmonics for the EUT. The 10 mA limit is also applied at this point and relaxes the test limit for the 4, 8, 10, 12 and 40th harmonics. In this example, 10 mA is 0.40% of fundamental and changes the 4th harmonic from failing to passing.

Column E provides an example of current harmonic data for an item of equipment tested under the distorted voltage condition.

Column F expresses whether the equipment has passed or failed the requirements for each specific harmonic. This is determined by the relationship between the current harmonics measured at the equipment input (column E) and the allowed current harmonics under distorted voltage input conditions (column D).

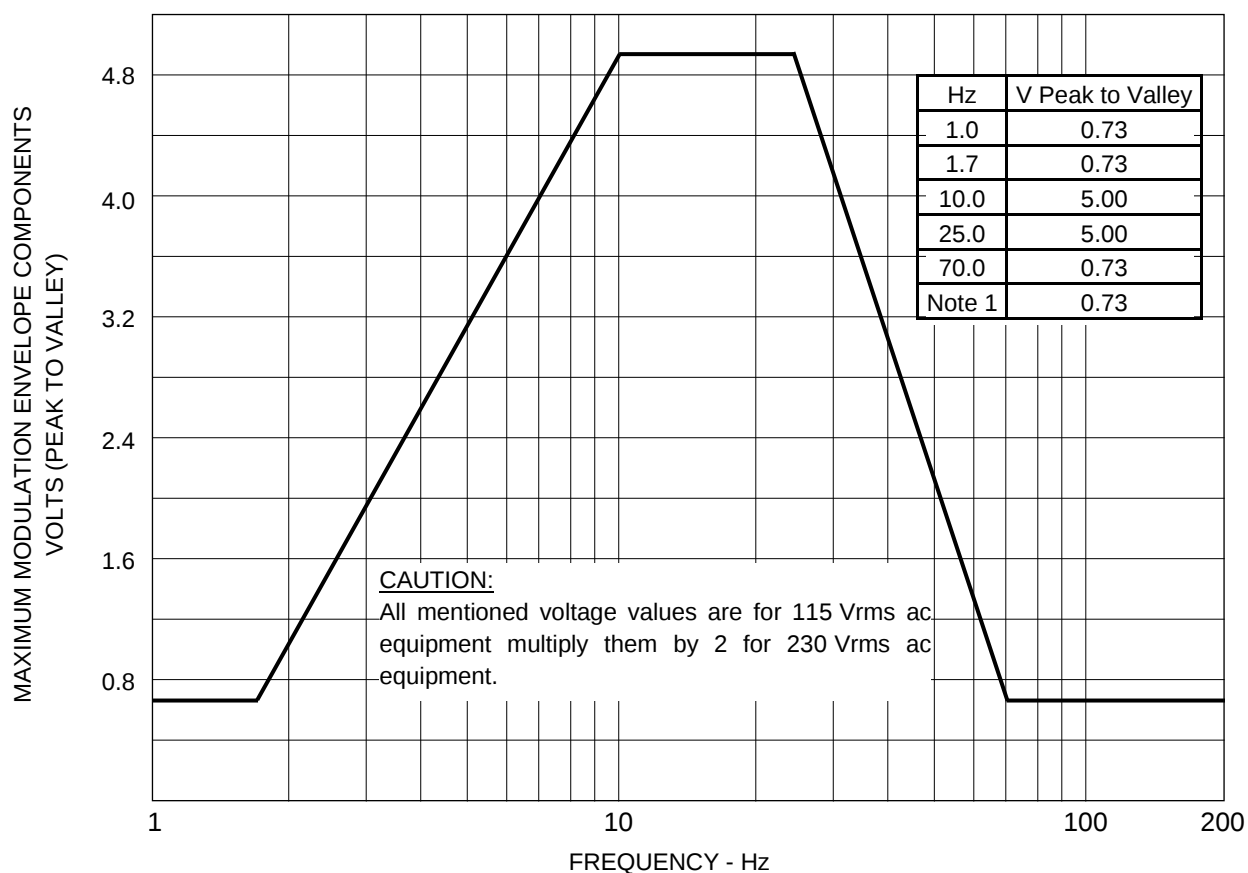
Table 16-7 Test Conditions for DC Equipment with Digital and Memory Circuits**Notes:**

1. Definitions:

 V_{NOM} Nominal voltage T_1 Duration of 1st interrupt (measured when voltage equals 50 % of V_{NOM}) T_3 Duration of 2nd interrupt (measured when voltage equals 50 % of V_{NOM})2. Tolerance to T_1 , T_2 , $T_3 = \pm 10\%$ except for test conditions 1 and 2 where 9000 msec is a minimum.

3. The rise and fall time "d" is measured between the 10% and 90% points of the waveform.

Test	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Cat A, D, Z	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cat B	Y	Y	Y	Y	N/A	Y	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A	N/A	N/A	N/A
T1 (ms)	9000	9000	10	10	10	20	20	20	20	50	50	50	50	100	100	150	150
T3 (ms)	20	50	10	50	100	10	50	100	170	10	50	100	140	50	90	10	40



*Note: The last tested frequency equals 200 Hz for A(CF) systems.
The last tested frequency in the curve above changes from 200 Hz to be 1/2 the applied line frequency for A(WF) and A(NF) systems.*

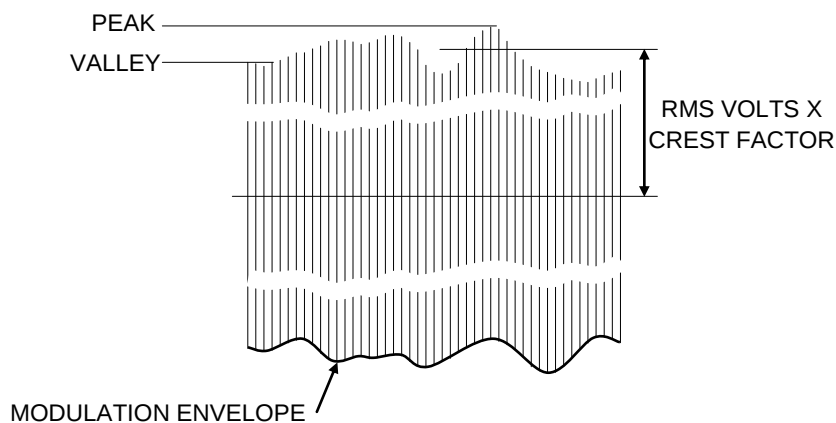


Figure 16-1 Frequency Characteristics of AC Voltage Modulation Envelope

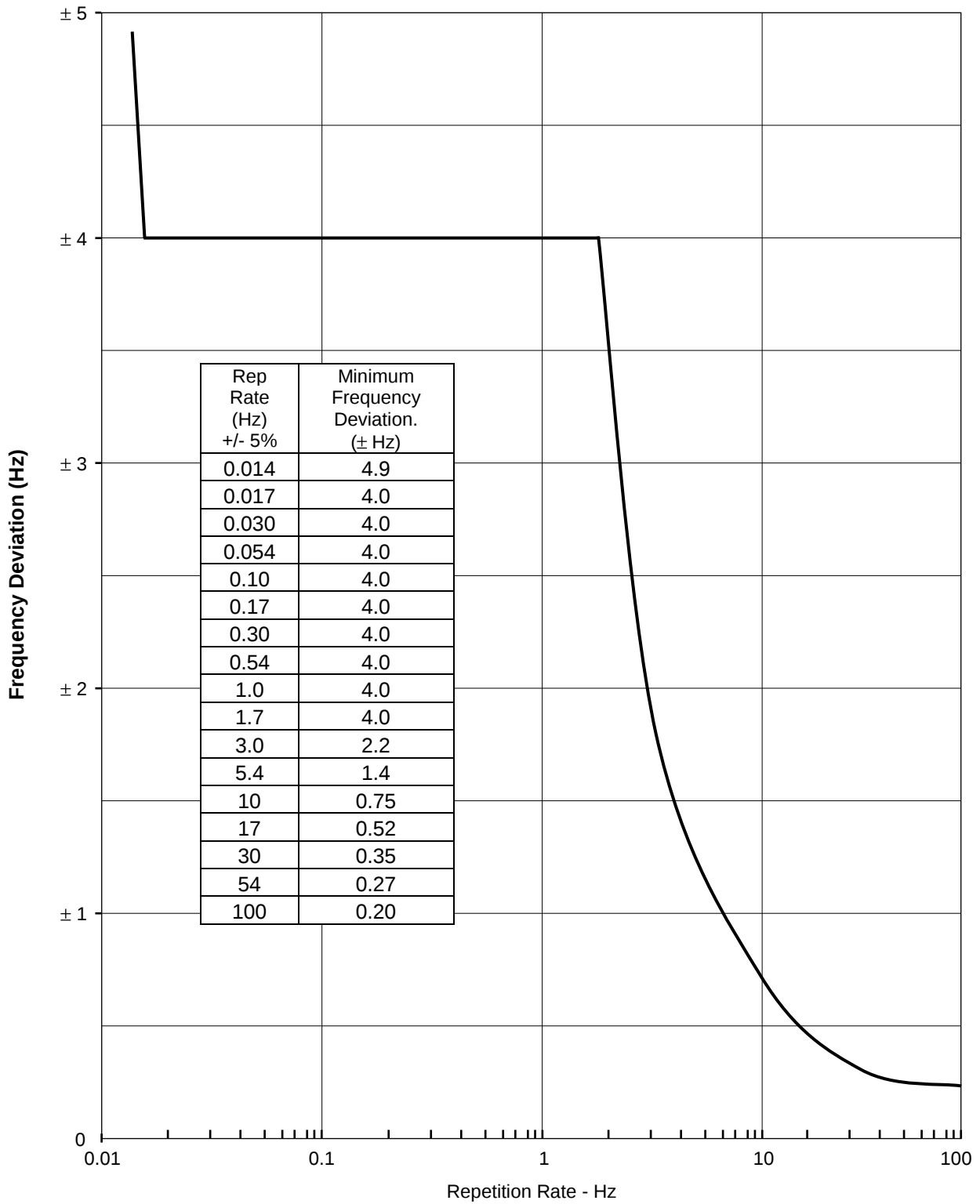
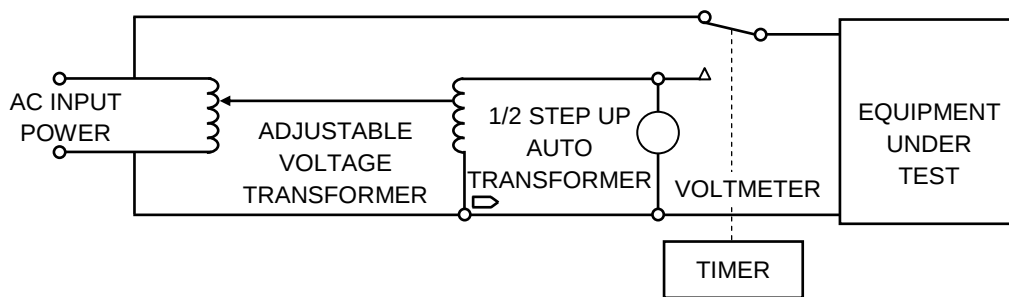
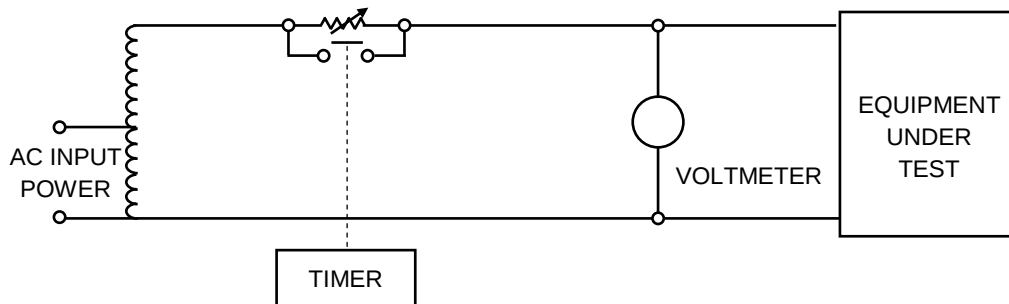


Figure 16-2 Characteristics of AC Frequency Modulation



CIRCUIT A

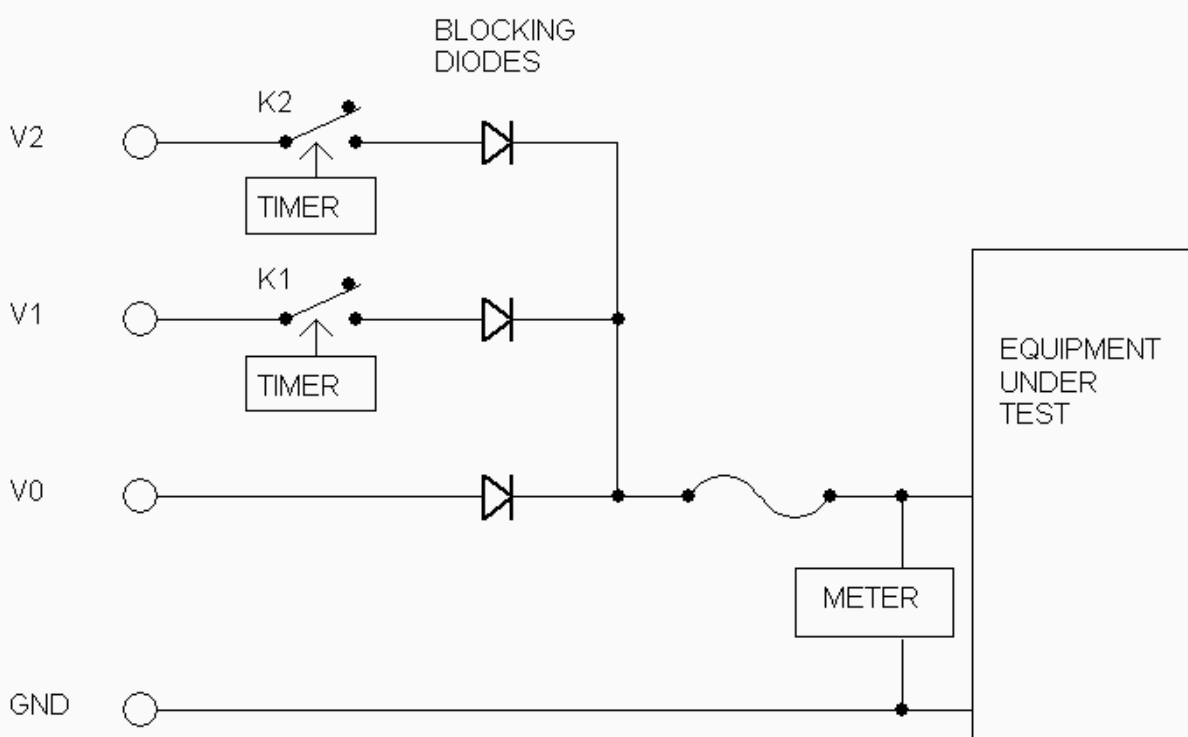
Note: Equipment under test will receive zero power during timer switching.



CIRCUIT B

Note: Circuit B is optional and can only be used when the source impedance is not critical to the equipment performance.

Figure 16-3 AC Equipment Surge Voltage Test



		VOLTAGE TO BE APPLIED TO EUT		
		VOLTAGE V0	VOLTAGE V1	VOLTAGE V2
K1 AND K2 STATE	K1	OPEN	CLOSED	OPEN
	K2	OPEN	OPEN	CLOSED

Notes:

1. Adjust timing of the K1/K2 state configuration to meet the duration of the voltage surge according to paragraph 16.6.1.4 (normal surge voltage) or paragraph 16.6.2.4 (abnormal surge voltage.)
2. K1 and K2 are to be actuated so that they are both closed at the start of the transition between V1 and V2.
3. The voltage sources are to provide enough current to reach the required test voltage as measured at the input to the EUT.
4. V0, V1 and V2 correspond to voltage values in the applicable test paragraphs. V0 is always lower than V1 and V2.
5. Optional resistors or active devices may exist from the cathodes of the diodes to ground to pull voltage down between voltage test steps.
6. Alternate test equipment which provides the required waveforms may be used.

Figure 16-4 DC Equipment Surge Voltage Test

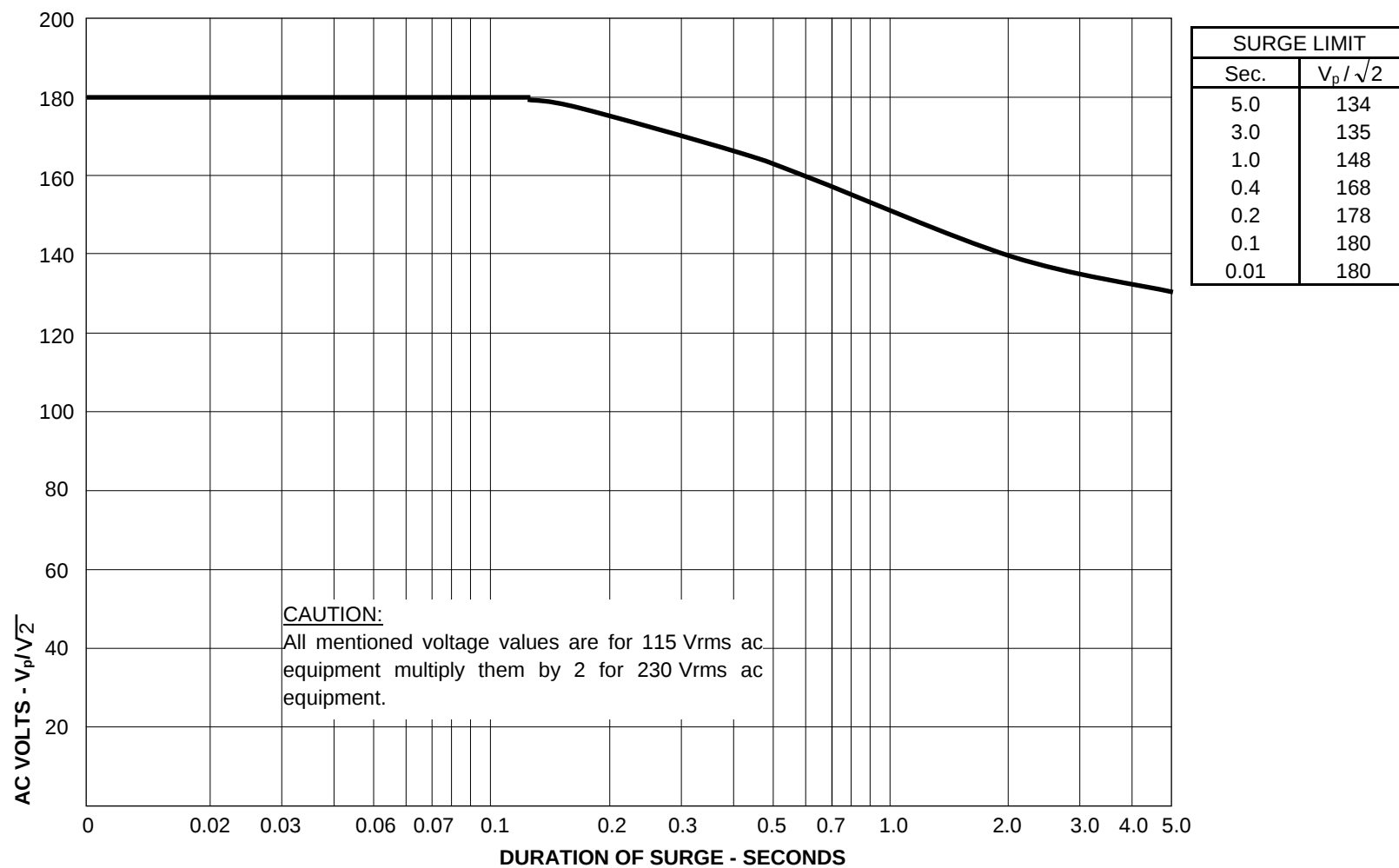
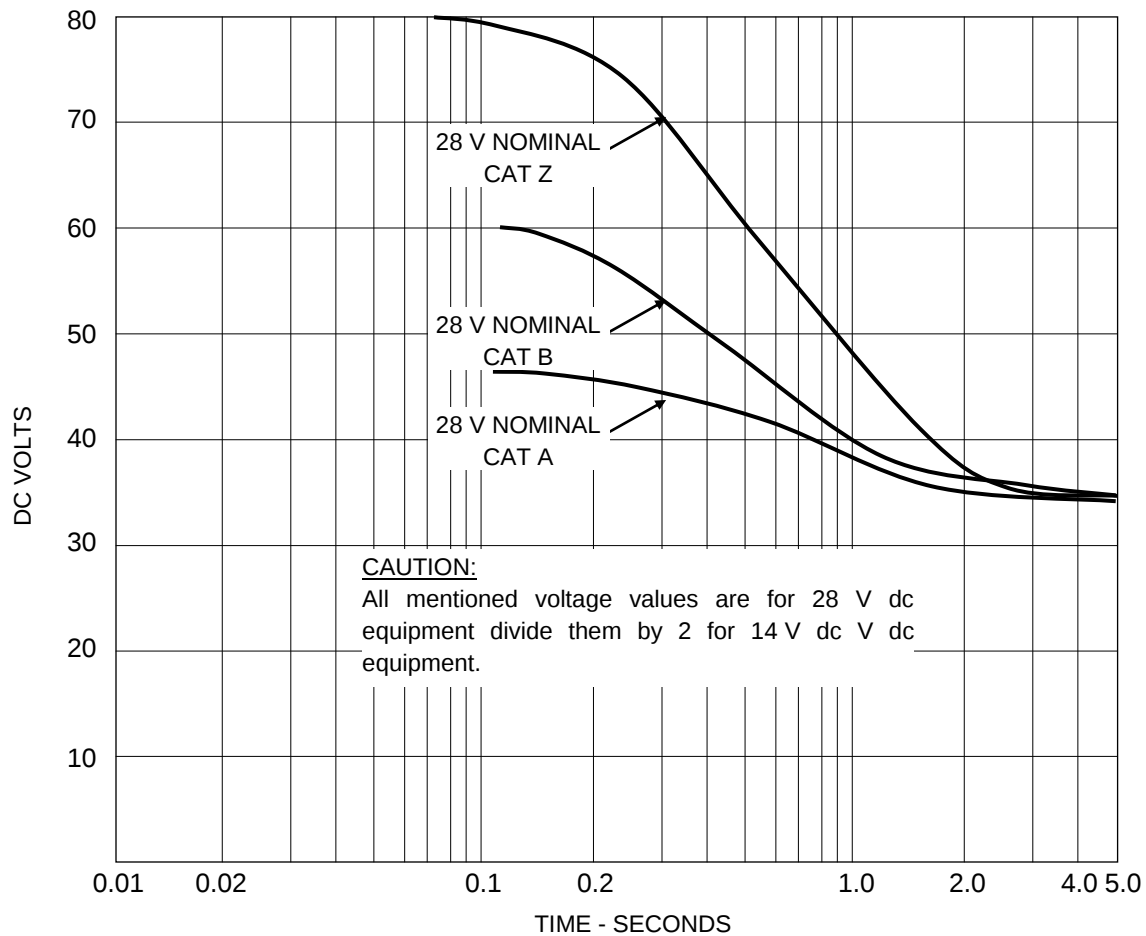


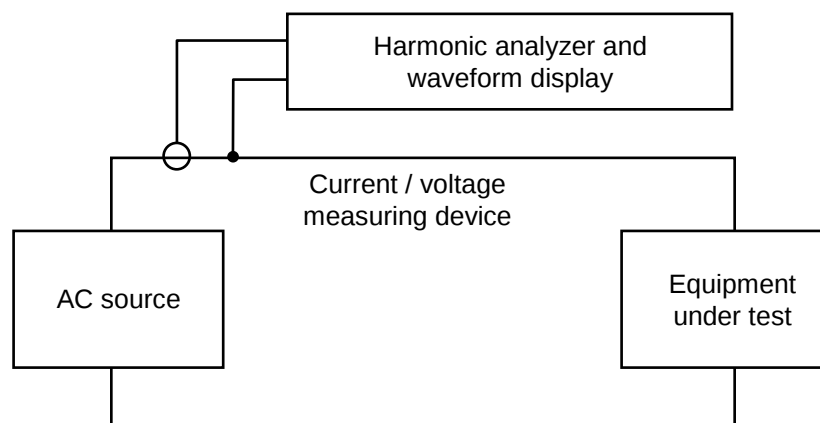
Figure 16-5 Envelope of AC Abnormal Voltage Surges



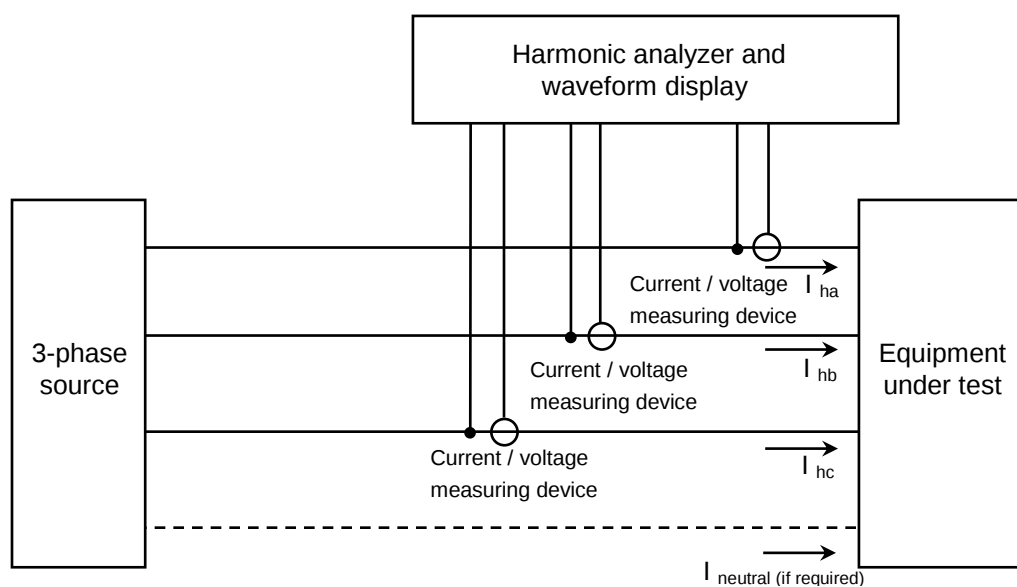
Note: Cat D has the same basic wave shape as Cat A.

SURGE LIMITS				
Sec.	Cat A	Cat B	Cat Z	Cat D
5.0	32.2	32.2	32.2	315
1	37.8	40	48	345
0.5	42.5	47	60	385
0.1	46.3	60	80	425

Figure 16-6 Typical Abnormal DC Surge Voltage Characteristics



Current Harmonic Measurement for Single Phase Equipment



Current Harmonic Measurement for Three Phase Equipment

Figure 16-7 Typical Current Harmonic Measurement Diagrams

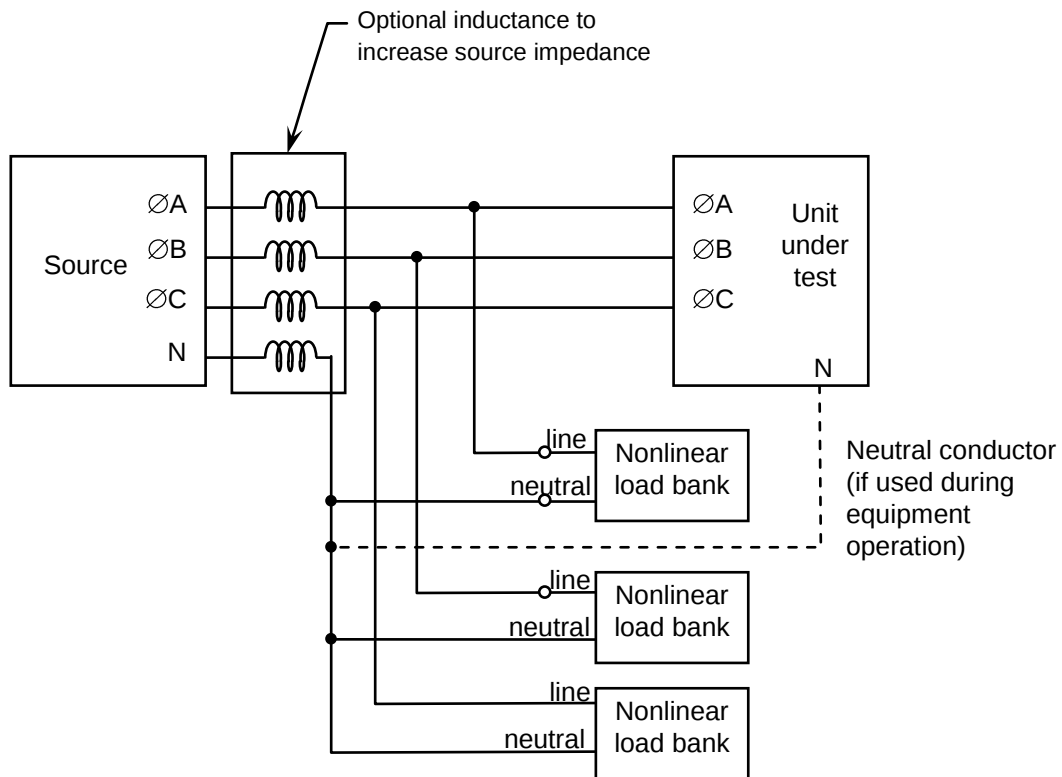
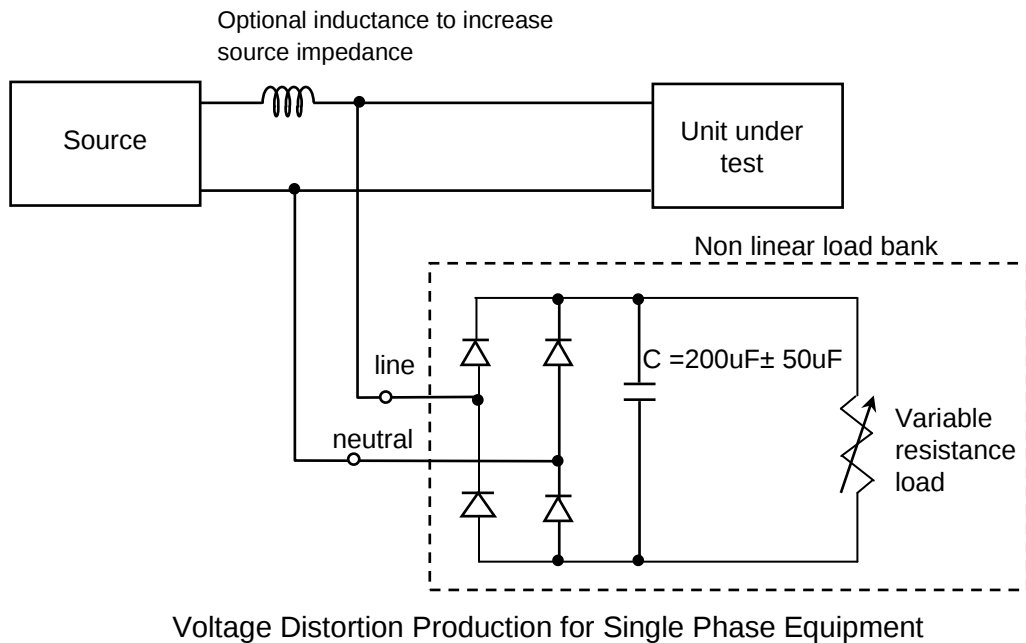
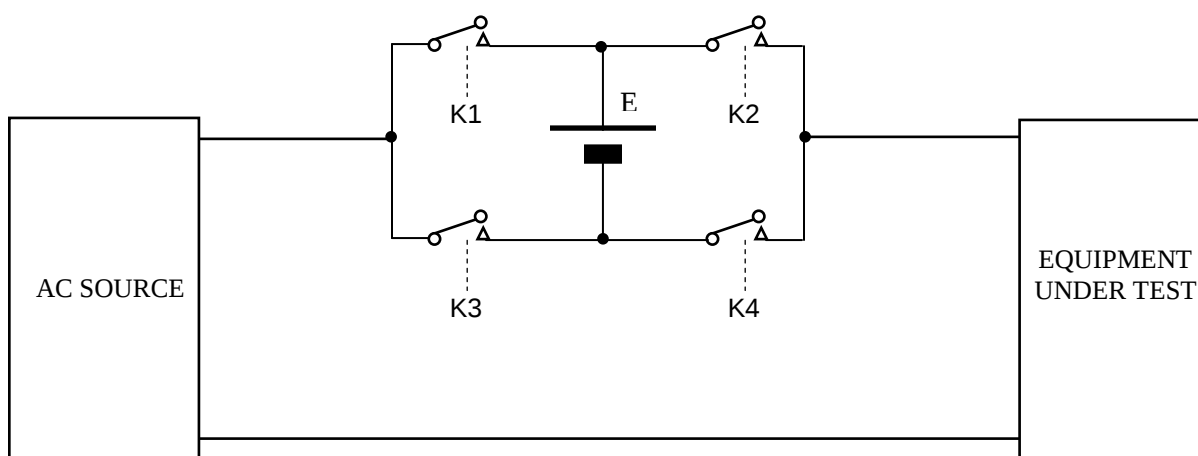


Figure 16-8 Typical Voltage Distortion Circuits for Harmonic Testing



DC VOLTAGE OFFSET PRODUCTION FOR SINGLE-PHASE EQUIPMENT

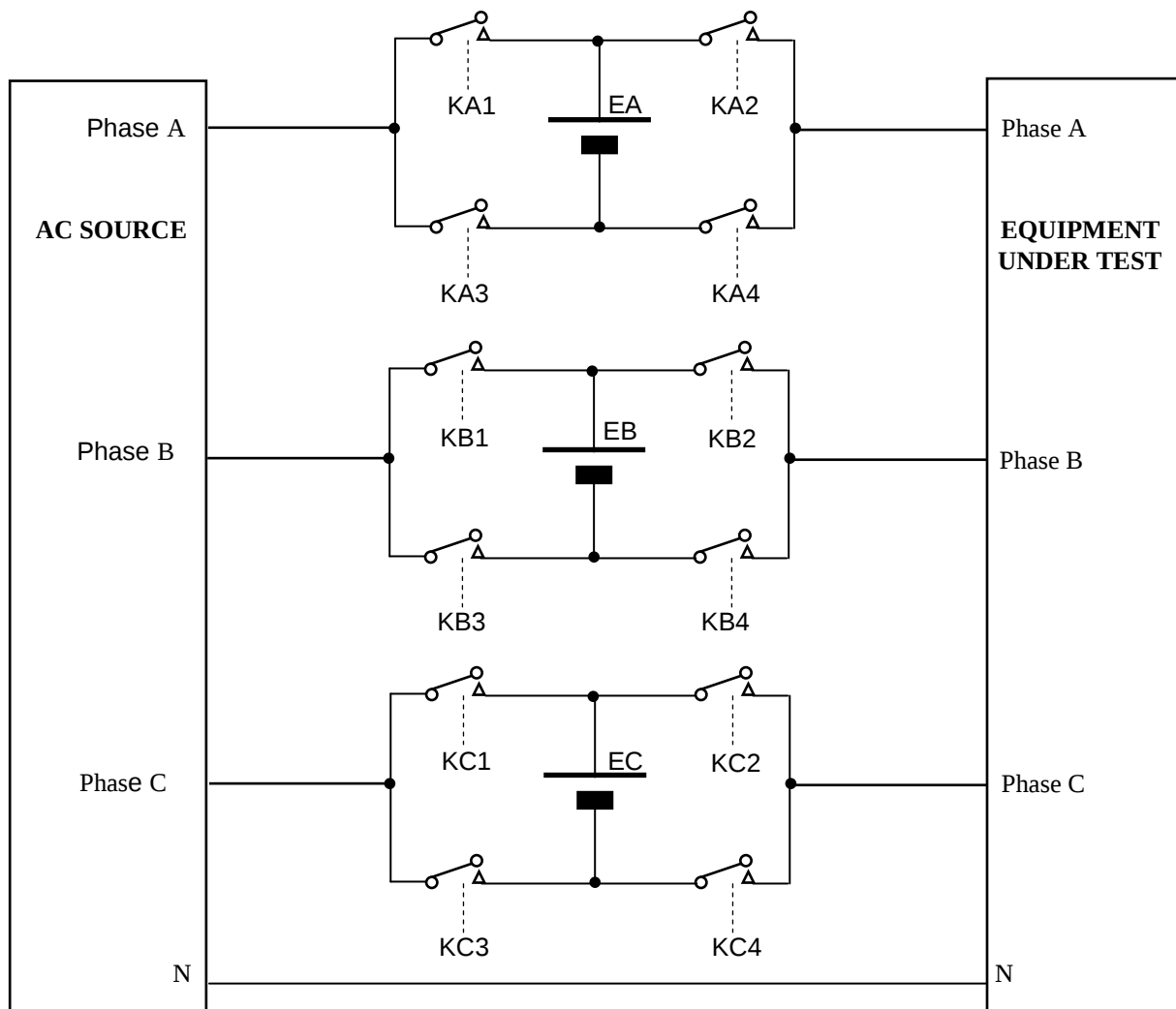
“E” corresponds to an adjustable DC voltage source. This source:

- Shall be compatible with the EUT maximum steady-state rms current obtained for all normal modes of operation.
- Shall create the following DC voltage offset on the AC source:
 - ◇ For 115V AC equipment: -0.200 ± 0.040 V dc and $+0.200 \pm 0.040$ V dc.
 - ◇ For 230V AC equipment: -0.200 ± 0.040 V dc and $+0.200 \pm 0.040$ V dc.

State of switches K1 to K4

- Initial power-up of EUT:
 - ◇ K1 and K2 (or K3 and K4) are closed in order not to submit E to the EUT inrush current.
- Test Condition: Application of negative DC content on the AC source
 - ◇ K1 and K4 are closed
 - ◇ K2 and K3 are open
- Test Condition: Application of positive DC content on the AC source
 - ◇ K1 and K4 are open
 - ◇ K2 and K3 are closed

Figure 16-9 AC Single-Phase Equipment DC Offset Test



DC Voltage Offset Production for Three-Phase Equipment

“EA”, “EB”, and “EC” correspond to adjustable DC voltage sources. These sources:

- Shall be compatible with the EUT maximum steady-state rms current obtained for all normal modes of operation.
- Shall create the following DC voltage offset on the AC source:
 - ◇ For 115V AC equipment: -0.200 ± 0.040 V dc and $+0.200 \pm 0.040$ V dc.
 - ◇ For 230V AC equipment: -0.200 ± 0.040 V dc and $+0.200 \pm 0.040$ V dc.

State of switches KA1 to KA4, KB1 to KB4 and KC1 to KC4

- Initial power-up of EUT:
 - ◇ KA1, KB1, KC1 and KA2, KB2, KC2 (or KA3, KB3, KC3 and KA4, KB4, KC4) are closed in order not to submit EA, EB and EC to the EUT inrush current
- Test Condition: Application of negative DC content on the AC source
 - ◇ KA1, KB1, KC1 and KA4, KB4, KC4 are closed
 - ◇ KA2, KB2, KC2 and KA3, KB3, KC3 are open
- Test Condition: Application of positive DC content on the AC source
 - ◇ KA1, KB1, KC1 and KA4, KB4, KC4 are open
 - ◇ KA2, KB2, KC2 and KA3, KB3, KC3 are closed

Figure 16-10 AC Three-Phase Equipment DC Offset Test

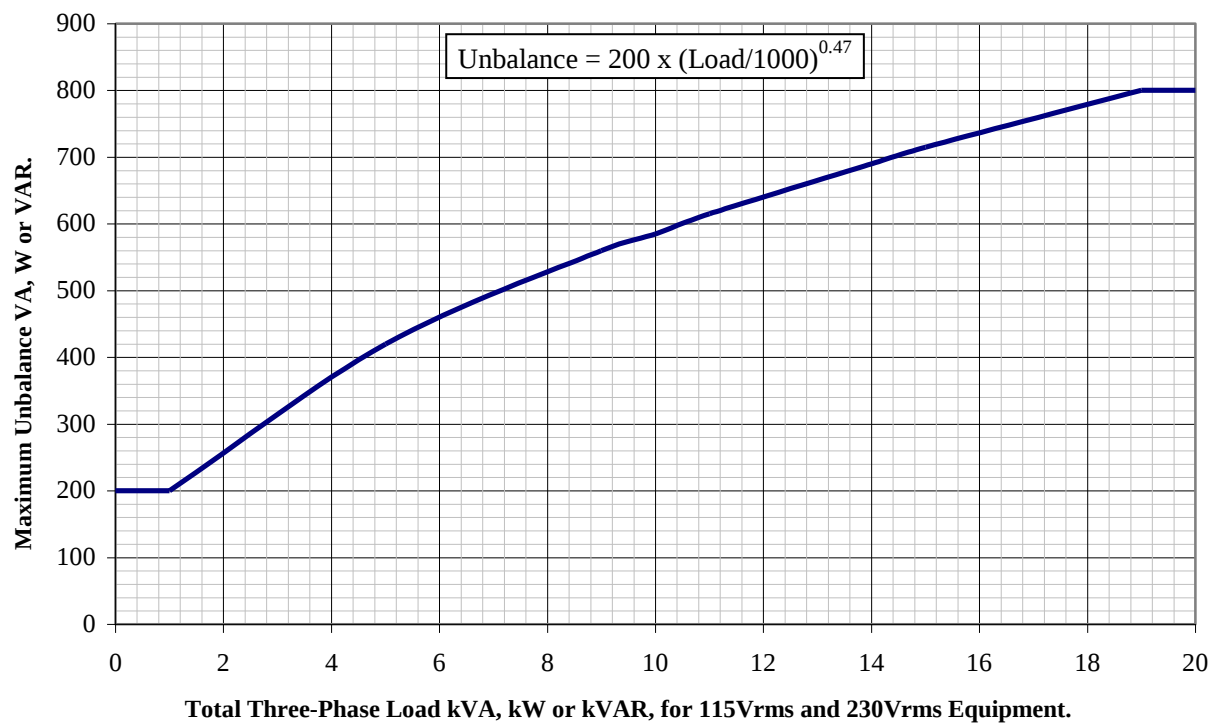
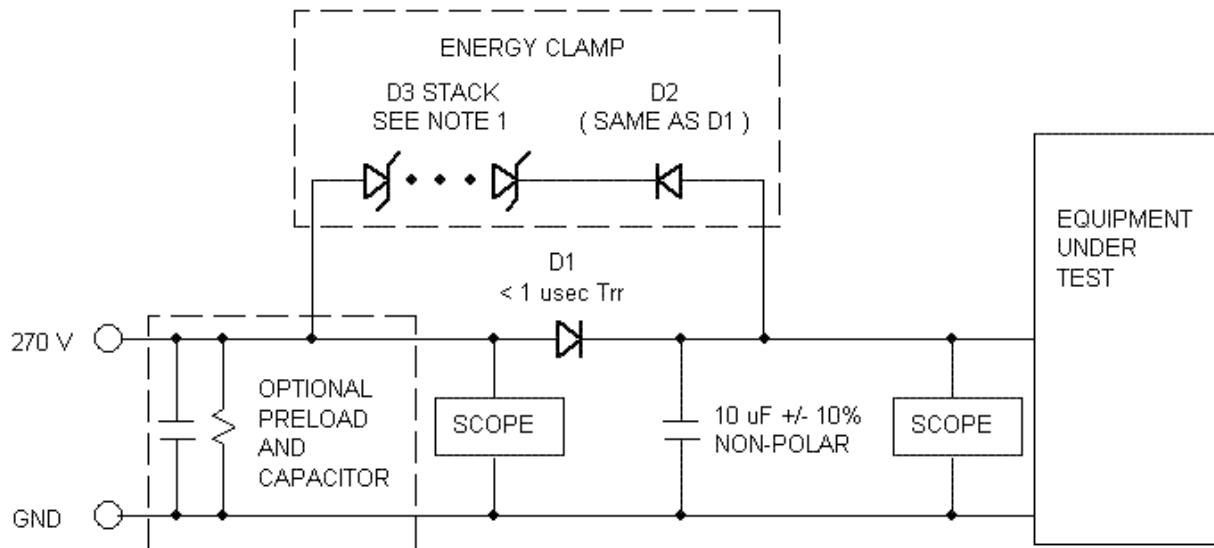


Figure 16-11 Allowable Phase Unbalance for Three Phase AC Loads



Notes:

1. The D3 zener / transorb stack shall have a measured reverse breakdown leakage current < 24 mA at 24V +/- 1 V dc as measured both before and after EUT testing. Uni-directional and/or bi-directional clamping devices may be used in the D3 stack.
2. Both D1 and D2 shall be rated for greater than the maximum EUT current draw and both shall have a reverse recovery time less than 1.0 μ sec.
3. The D3 zener / transorb stack shall be rated for a 1 msec pulse current greater than the EUT maximum current draw.
4. Verify that potential ground loops through oscilloscope do not cause reading errors and/or damage to the oscilloscope.

CAUTION:

1. Potentially lethal voltages appear on both sides of the diodes and on the 10 μ F capacitor.
2. EUTs that fail this test may cause the test set-up to explode. Install and use appropriate electrical and mechanical safe guards before running this test.
3. Before attempting to test an EUT for regenerated energy, verify with the EUT's manufacture that the EUT was designed to pass this test.

Figure 16-12 270 V dc Regenerated Energy Test Setup

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 17

Voltage Spike

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2 and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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December 8, 2010

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17.0 Voltage Spike

17.1 Purpose of the Test

This test determines whether the equipment can withstand the effects of voltage spikes arriving at the equipment on its power leads, either ac or dc. The main adverse effects to be anticipated are:

- a. Permanent damage, component failure, insulation breakdown.
- b. Susceptibility degradation, or changes in equipment performance.

17.2 Equipment Categories

Category A

Equipment intended primarily for installation where a high degree of protection against damage by voltage spikes is required is identified as Category A.

Category B

Equipment intended primarily for installations where a lower standard of protection against voltage spikes is acceptable is identified as Category B.

17.3 Test Setup and Apparatus

The transient generator used shall produce the waveform shown in Figure 17-1. A typical test setup is shown in Figure 17-2. Any method of generating the spike may be used if the waveform complies with Figure 17-1.

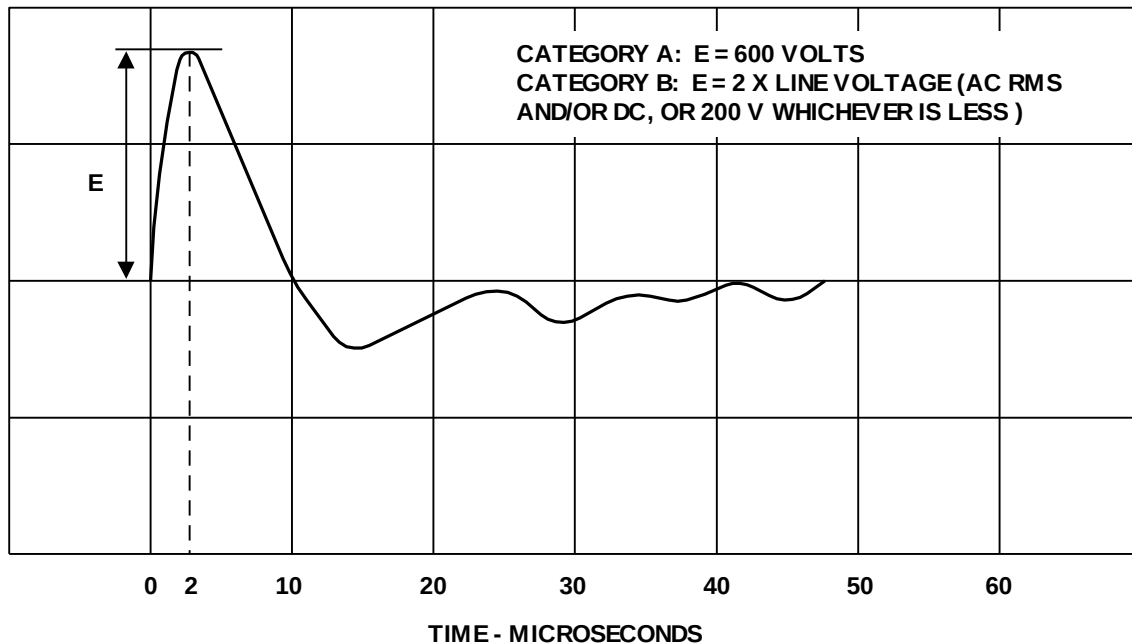
17.4 Test Procedure

With the equipment under test disconnected, the transient wave shape shall be verified to be in accordance with Figure 17-1.

With the equipment operating at its design voltage(s), apply to each primary power input a series of positive and negative spikes described in Figure 17-1. In the case where multiple power inputs are supplied by the same bus, all connections for these inputs shall be tested simultaneously. Apply a minimum of 50 positive polarity transients within a period of one minute. Repeat the application with 50 negative polarity transients within a one minute period. The time between positive and negative transient applications is not germane to the intent of the test, and is left to the discretion of the tester. Repeat the test for each operating mode or function of the equipment.

After application of the spikes, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

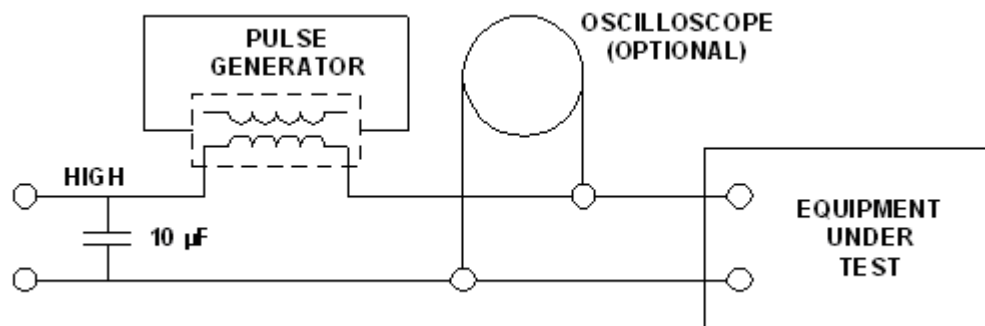
NOTE: If performance is measured during the application of this test, then the performance requirements contained in the applicable equipment performance standard apply.



THE GENERATOR SOURCE IMPEDANCE SHALL BE 50Ω NOMINAL. THE SPECIFIED VOLTAGE AND DURATIONS ARE FOR OPEN CIRCUIT CONDITIONS ONLY. THE PEAK VOLTAGE MAY BE SUBSTANTIALLY LOWER WITH THE EQUIPMENT CONNECTED. THE GENERATOR SOURCE IMPEDANCE SHALL BE VERIFIED BY TESTING WITH A 50Ω ±10% LOAD RESISTOR, AND SHALL PRODUCE ONE HALF OF THE SPECIFIED VOLTAGE ±10%.

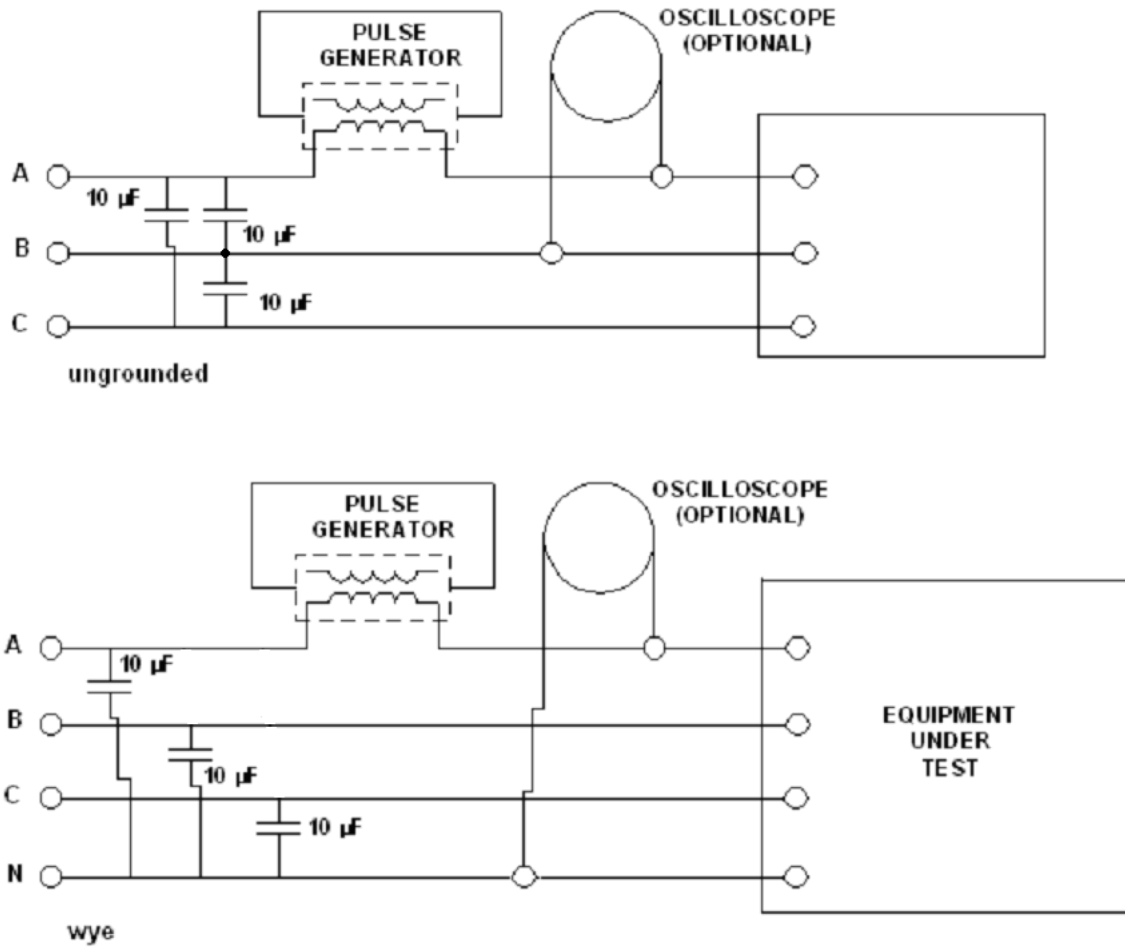
Note: The waveform shown above is typical. The waveform requirement is accomplished if the pulse rise time is less than or equal to 2μsec and the total pulse duration is at least 10μsec.

Figure 17-1 Voltage Spike Waveform



NOTE: FOR EQUIPMENTS DRAWING HIGH CURRENTS, ALTERNATE TEST METHODS MAY BE REQUIRED (To avoid saturating transformer etc.).

Figure 17-2 Voltage Spike Test Setup, DC or single phase AC



NOTE: FOR EQUIPMENTS DRAWING HIGH CURRENTS, ALTERNATE TEST METHODS MAY BE REQUIRED (To avoid saturating transformer etc.).

Figure 17-3 Voltage Spike Test Setup, three phase AC

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 18

Audio Frequency Conducted Susceptibility

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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18.0 Audio Frequency Conducted Susceptibility - Power Inputs (Closed Circuit Test)

18.1 Purpose of the Test

This test determines whether the equipment will accept frequency components of a magnitude normally expected when the equipment is installed in the aircraft. These frequency components are normally harmonically related to the power source fundamental frequency.

18.2 Equipment Categories and Frequency Classes

18.2.1 Equipment Categories

Test designation for equipment consists of:

Category reference:

- For ac equipment: R(CF), R(NF) or R(WF)
- For dc equipment: R, B, or Z

Categories R(CF), R(NF), R(WF) and R

Equipment intended for use on aircraft electrical systems where the primary power is from a constant or variable frequency ac system and where the dc system is supplied from transformer-rectifier units, is identified as:

- for ac equipment: Category R(CF), R(NF) or R(WF),
- for dc equipment: Category R.

Category B

Dc equipment intended for use on aircraft electrical systems supplied by engine-driven alternator/rectifiers, or dc generators where a battery of significant capacity is floating on the dc bus at all times, is identified as Category B. Unless otherwise specified, tests levels for 14 Vdc equipment are half those shown for 28 Vdc equipment.

Category Z

Dc equipment that may be used on all other types of aircraft electrical systems applicable to these standards is identified as Category Z. Category Z shall be acceptable for use in place of Category R or B. Examples of this category are dc systems supplied from variable-speed generators where:

- a. The dc power supply does not have a battery floating on the dc bus, or
- b. Control or protective equipment may disconnect the battery from the dc bus, or,
- c. The battery capacity is small compared with the capacity of the dc generators.

Category K

Equipment intended for use on aircraft electrical systems where the primary power is from a constant or variable frequency ac system and characterized by a voltage distortion level higher than the one for the ac supplies applied on category R equipment.

Category K shall be acceptable for use in place of Category R.

18.3 Test Procedures

Unless otherwise specified, the EUT shall be supplied at the nominal input voltage during performance of the following tests.

18.3.1 DC Input Power Leads

- a. For Categories R, B, and Z, connect the equipment under test as shown in Figure 18-1. While the equipment is operating, apply a sine wave audio frequency signal successively in series with each ungrounded dc input power lead. While varying the audio frequency of the applied signal and with the peak-to-peak amplitude of this signal at the value specified in Figure 18-3 or Figure 18-4, (as appropriate) and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.
- b. For 270V Category Z, connect the equipment under test as shown in Figure 18-1 with the 270V negative lead(s) attached to ground. While the equipment is operating, apply a sine wave audio frequency signal successively in series with each positive dc input power lead. Unless otherwise specified in the applicable performance standards, the negative lead shall be connected to ground for this test. While varying the audio frequency of the applied signal and with the peak to peak amplitude of this signal at the value specified in Figure 18-3 and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.
- c. For 270V Category Z equipment, connect the equipment under test as shown in Figure 18-2, and repeat test category over the required frequency range with voltage ripple applied common mode for all 270V dc equipment. (Note that the negative lead(s) is connected to ground through the coupling transformer). The common mode test level is to be twice the differential test level (Figure 18-3). While scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

18.3.2 AC Input Power Leads

- a. For R(CF) and K category Equipment

Connect the equipment under test as shown in Figure 18-1. While the equipment is operating, apply a sine wave audio frequency signal successively in series with each ungrounded ac input power lead. While varying the frequency of the applied signal between 700 Hz and 16 kHz, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

For R(CF) Category equipment, maintain the rms amplitude of this signal at not less than 6% of the maximum normal ac input voltage and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

For K Category equipment, maintain the rms amplitude of this signal at not less than 8% of the maximum normal ac input voltage up to 7.6 kHz and 6% above 7.6 kHz, and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

b. For R(NF) and K category equipment:

- (1) Connect the equipment under test as shown in Figure 18-1. While equipment operating with a power source frequency of 360 Hz $\pm 5/0$ Hz, apply a sine wave audio frequency signal successively in series with each ungrounded ac input power lead, while varying the frequency of the applied signal between 700 Hz and 26 kHz.

For R(NF) Category equipment, maintain the rms amplitude of this signal at not less than 6% of the maximum normal ac input voltage, and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

For K Category equipment, maintain the rms amplitude of this signal at not less than 8% of the maximum normal ac input voltage up to 12.4 kHz and 6% above 12.4 kHz, and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

- (2) Repeat test (1) with a power source frequency of 650 Hz $\pm 0/5$ Hz while varying the frequency of the applied signal between 1100 Hz and 32 kHz.

c. For R(WF) and K category equipment:

- (1) Connect the equipment under test as shown in Figure 18-1. While equipment operating with a power source frequency of 360 $\pm 5/0$ Hz, apply a sine wave audio frequency signal successively in series with each ungrounded ac input power lead, while varying the frequency of the applied signal between 700 Hz and 32 kHz.

For Category R(WF) and K Category equipment, maintain the rms amplitude of this signal at not less than 8% of the maximum normal ac input voltage up to 15.2 kHz and 6 % above 15.2 kHz, and while scanning at the rate specified in 18.3.3, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Repeat this test for all operating modes as specified in 18.3.3.

- (2) Repeat test (1) with a power source frequency of 800 Hz $\pm 0/5$ Hz while varying the frequency of the applied signal between 1400 Hz and 32 kHz.

18.3.3 Frequency Scan Rates

For test equipment that generate discrete frequencies the minimum number of test frequencies shall be 30 frequencies per decade. The test frequencies shall be logarithmically spaced. As an example, a formula that can be used to calculate these frequencies for 30 steps per decade in ascending order is:

$$f_{n+1} = f_1 * 10^{(n/30)} \pm 1\%$$

Where

f_n is a test frequency and $n = 1$ to m

f_1 is the start frequency

f_m is the end frequency

$m = 1 + 30 * \log(f_m/f_1)$.

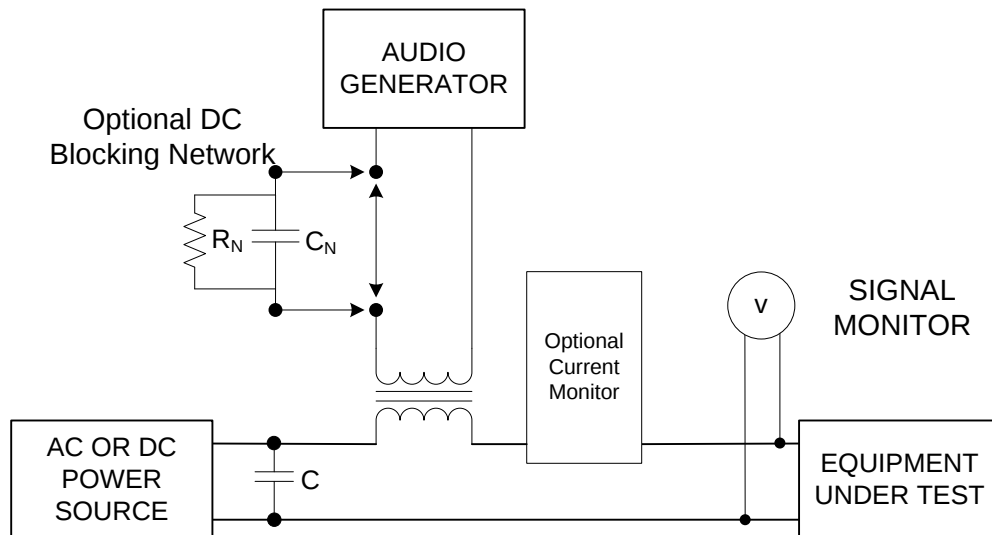
The dwell time at each test frequency shall be at least one minute, exclusive of test equipment settling time. If the last test step for F_{n+1} yields a frequency greater than f_m , round down to f_m .

For test equipment that generate a continuous linear frequency sweep, the minimum (i.e., fastest) sweep rate shall be equal to the number of discrete frequencies per decade (m) multiplied by two times the dwell time, i.e., 30 discrete frequencies per decade times 2 times 1 minute dwell time equals 60 minutes per decade sweep rate.

These tests shall be performed for the equipment operating modes that draw maximum steady state current and minimum steady state current from the prime power system. Where the ratio between maximum steady state current to minimum steady state current is 2:1 or less, then only one test at maximum steady state current is required.

18.4 General Remarks

- a. If the impedance to the test power leads is such that excessive induced current will be required to generate the specified audio signal voltage level, the test conditions will be adequately satisfied if the peak to peak induced current is limited to at least 36 amps. This peak to peak current is in addition to the current the EUT normally draws from the power source.
- b. For dc input power leads, paragraph 18.3.1, a large capacitor (100 microfarads or more) shall be connected across the dc power source. For ac input power a 10 microfarad capacitor shall be connected across the power source.
- c. Multiple primary power input connections that are intended to be tied in parallel external to the UUT in the installation shall be tested simultaneously.



Notes:

$C \geq 100$ microfarads for DC power only

$C \geq 8$ microfarads for AC power only

The Optional DC Blocking Network (C_N and R_N) shall not affect the achieved test levels

The Optional Current Monitor is intended to measure the AC portion of the audio frequency current, and not the EUT current draw

Figure 18-1 Test Setup for Audio Frequency Conducted Susceptibility Test (For AC and DC Power Lines, Differential Mode)

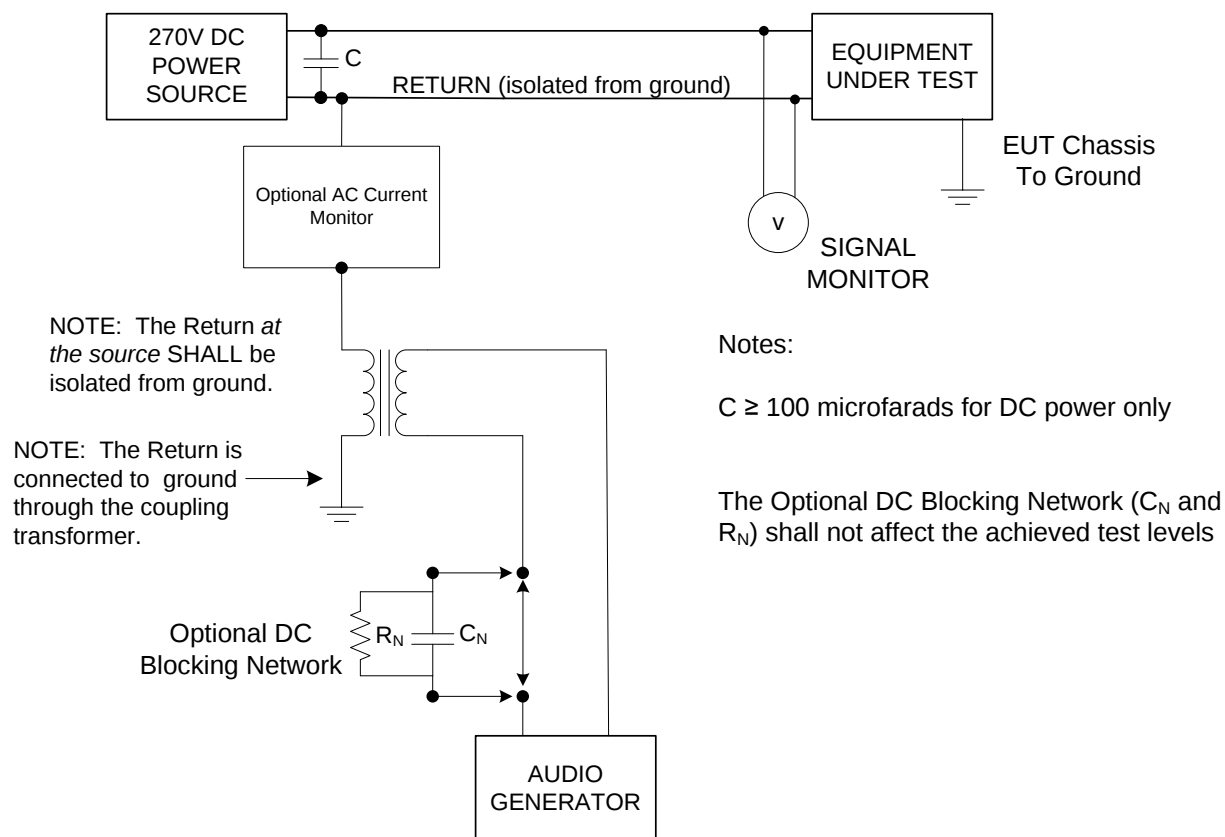


Figure 18-2 Test Setup for Audio Frequency Conducted Susceptibility Test (For 270V DC Power Lines, Common Mode)

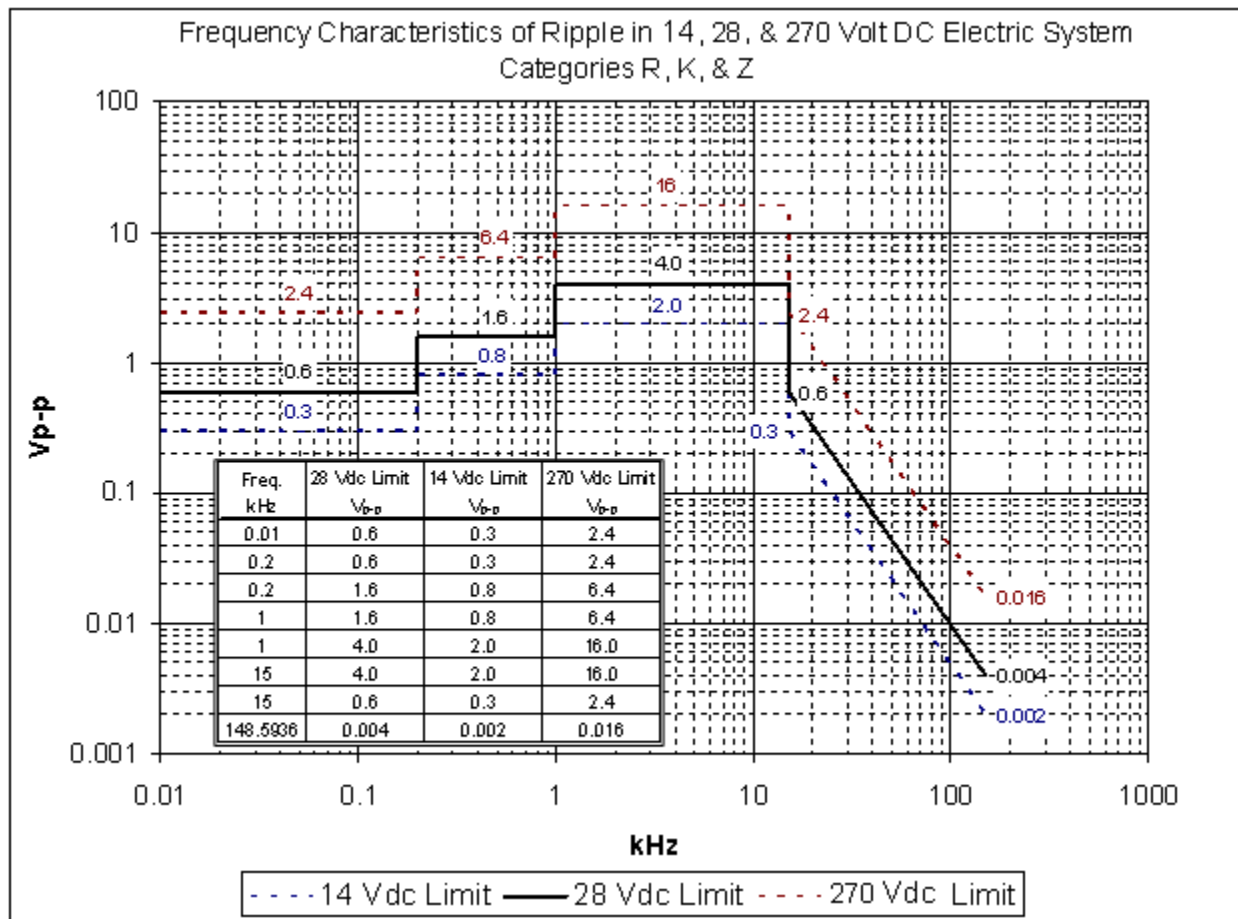


Figure 18-3 Frequency Characteristics of Ripple in 28 & 270 Volt DC Electric System — Categories R, K, & Z

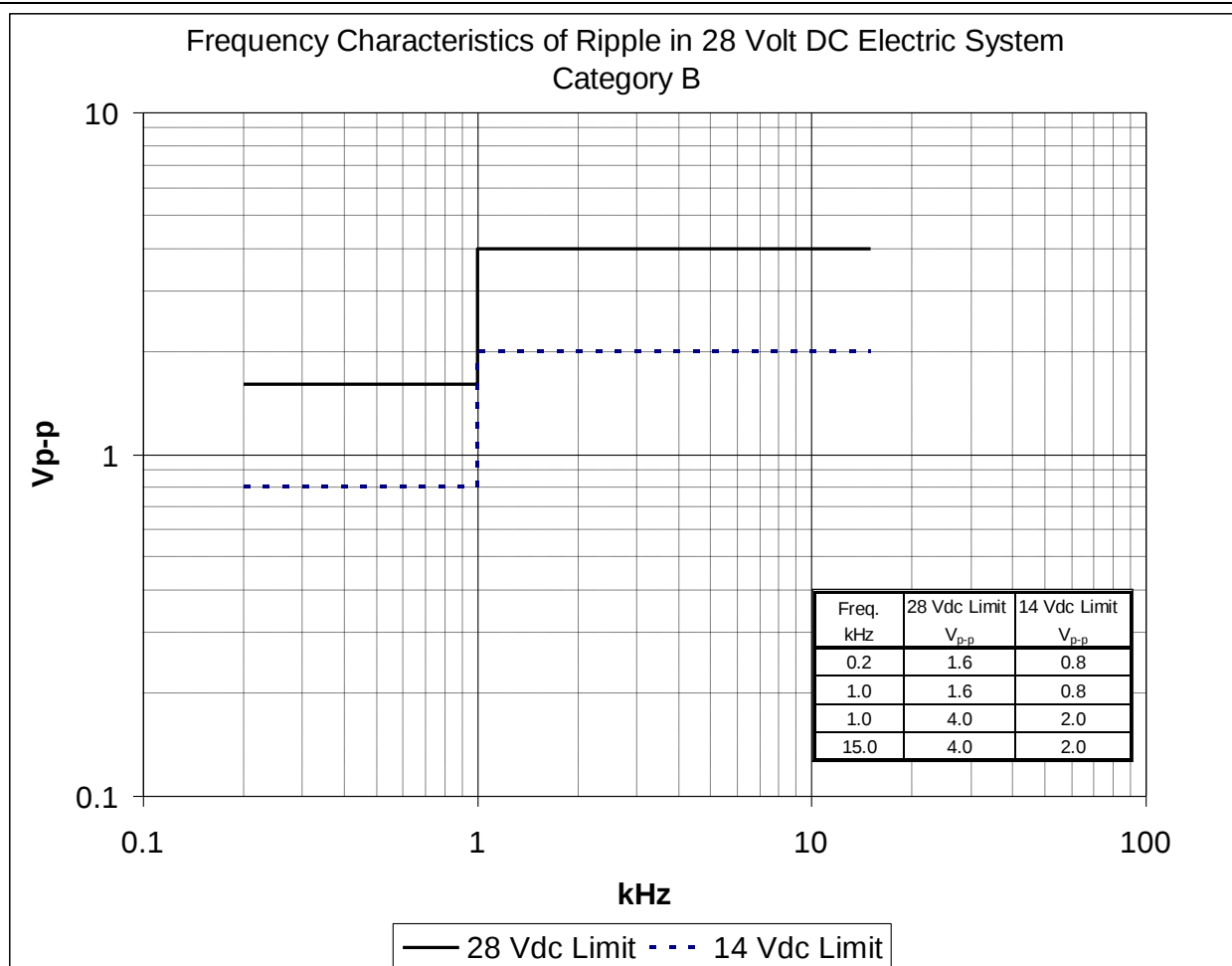


Figure 18-4 Frequency Characteristics of Ripple in 28 Volt DC Electric System — Category B

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

User's Guide Appendix 18

Audio Frequency Conducted Susceptibility – Power Inputs

**Based on
DO-160G Section 18.**

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Supersedes: RTCA/DO-160F
Prepared by: RTCA SC-135

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User's Guide, Appendix 18

Section 18 defines the environment, test procedures and requirements. In order to properly interpret the procedures and requirements outlined in Section 18, a User's Guide is provided in Appendix 18.

The User's Guide includes rationale, guidance and background information for the environment, test procedures and requirements, guidance in applying the requirements, and lessons learned from aircraft and laboratory experience. This information should help user's understand the intent behind the requirements, should aid in tailoring requirements as necessary for particular applications and should help user's develop detailed test procedures based on the general test procedures in Section 18.

The User's Guide follows a parallel format to the main body of Section 18 for easy cross reference. Paragraph numbers corresponding to each paragraph in Section 18 are included the User's Guide. Where there is no additional information provided in the User's Guide, the paragraph header is provided but the following paragraph is left blank.

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18.A.0 Audio Frequency Conducted Susceptibility - Power Inputs**18.A.1 Purpose of the Test**

This section of DO-160 is intended to provide test procedures and test levels that can be used to test equipment for audio frequency conducted susceptibility of power input lines. It is the responsibility of the installer to make sure the test results satisfy the certification requirements of the proposed installation. This user's guide does not contain requirements; it is intended to provide background information and considerations that improve the likelihood of successful test results.

18.A.2 Equipment Categories and Frequency Classes

For AC equipment, Categories R(CF), R(NF), and R(WF) correspond to Categories A(CF), A(NF), and A(WF) in section 16, respectively.

For DC equipment, Categories R, B, and Z correspond to Categories A, B, and Z in section 16, respectively.

18.A.2.1 Equipment Categories**18.A.3 Test Procedures**

- a. In some installations, the power return is not connected locally to the ground plane, but rather, is isolated from ground. In these cases, it may become necessary to isolate the voltage measurement device from ground in order to properly measure the injected signal. Several methods exist to isolate the voltage measurement device, including the use of differential probe amplifiers and isolation transformers inline with the power input to the measurement device. The benefit to the use of a differential probe amplifier is that it does not present a potential shock hazard, as does the use of an isolation transformer on the power input to the measurement device.

18.A.3.1 DC Input Power Leads**18.A.3.2 AC Input Power Leads**

- a. Phase shifting networks (PSN) should generally be avoided when performing this test. PSNs introduce extra elements in the measurement path, and can introduce errors in measurement resulting in either overtest or undertest, if not tuned properly.
- b. The figures in section 18 show all measurements being taken across the EUT **INPUT TERMINALS**. While the capacitor across the power supply serves to provide a low impedance for the AFCS test signal, so that most of the AFCS signal delivered to the system is applied to the EUT, there is still an impedance associated with the supply and capacitor. Kirchoff's voltage law states that the voltage input across the secondary winding of the isolation transformer will be equal to the sum of the voltages across the EUT and the capacitor/power supply combination. This results in the voltage across the EUT being lower than the voltage across the secondary winding of the isolation transformer. For this reason, measurements should not be taken across either the secondary winding of the transformer, or "voltage measurement windings", if present, on the transformer.

18.A.3.3 Frequency Scan Rates

The test steps per decade and dwell times were determined as the optimum values based on “best” designs and “worst” designs. In the case of a “worst” design, more steps are needed to find all of the failure points. In the case of “best” designs, the longer dwell times are needed to induce overheating in damping elements of the input power circuitry.

18.A.4 General Remarks

- a. The 36 Amp (peak-to-peak) current limit is based on the 100Wrms power limit and 0.6 Ohm rated impedance present in DO-160E. Both originated from test equipment historically used during performance of this test. 36Ap-p is derived from 100Wrms as follows:

$$P_{rms} = (I_{rms}^2) * Z$$
$$I_{p-p} = I_{rms} * (\text{sqrt } 2) * 2$$

$$100W_{rms}, \text{ across } 0.6 \text{ ohms: } \text{sqrt}(100W / 0.6 \text{ ohm}) = 12.91A_{rms} = 36.52 \text{ amp}_{pk-pk}$$

- b. The 0.6 ohm rated impedance is based on legacy equipment used during the early versions of this test. The tube amplifiers used when these specifications were standardized had roughly a 2 – 2.5 ohm output impedance, which resulted in a 0.5 – 0.6 ohm rated load impedance on the secondary winding of the isolation transformer.
- c. When a transformer is used to couple the audio frequency energy into the power lead, it must be capable of performing adequately when the ac or dc load current drawn by the equipment under test flows through its secondary winding.
- d. On AC lines, phase shifting networks should not be used, due to the potential for inaccurate measurements when using these devices.
- e. Caution must be exercised so that reflected voltages developed by input power current do not damage the audio power source generation system.
- f. The dc offset of the audio generator feeding the transformer can cause the audio generator and/or transformer to overheat and fail. A capacitor paralleled with a 1 Ohm resistor inserted between the audio generator and transformer will prevent this problem. Both the capacitor and resistor must be rated for the current passing through it. The capacitor must be low enough in impedance to allow the required test levels to be achieved.

**Figure 18-A-1 Test Setup for Audio Frequency Conducted Susceptibility Test
(For AC and DC Power Lines, Differential Mode)**

- a. The current monitor is listed as optional to allow test conductors to only monitor test voltage during test, despite the risk for over test. The risk in this practice is that the possibility exists of the EUT input filtering becoming resonant at the AFCS signal frequency, and requiring currents greater than 36Ap-p to reach the desired test voltage, resulting in potential damage to the EUT.

**Figure 18-A-2 Test Setup for Audio Frequency Conducted Susceptibility Test
(For 270V DC Power Lines, Common Mode)**

- a. The current monitor is listed as optional to allow test conductors to only monitor test voltage during test, despite the risk for over test. The risk in this practice is that the possibility exists of the EUT input filtering becoming resonant at the AFCS signal frequency, and requiring currents greater than 36Ap-p to reach the desired test voltage, resulting in potential damage to the EUT.

**Figure 18-A-3 Frequency Characteristics of Ripple in 28 & 270 Volt DC Electric System —
Categories R, K, & Z**

Figure 18-A-4 Frequency Characteristics of Ripple in 28 Volt DC Electric System — Category B

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 19

Induced Signal Susceptibility

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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19.0 Induced Signal Susceptibility**19.1 Purpose of the Test**

This test determines whether the equipment interconnect circuit configuration will accept a level of induced voltages caused by the installation environment. This section relates specifically to interfering signals related to the power frequency and its harmonics, audio frequency signals, and electrical transients that are generated by other on-board equipment or systems and coupled to sensitive circuits within the EUT through its interconnecting wiring. Power leads tested under Section 18 are exempt from this test.

19.2 Equipment Categories

The induced signal susceptibility tests category is defined with three letters. The first letter (C, Z, A or B) refers to the test level; the second letter (C, N or W) refers to the type of primary power supply installation; and the third letter (E or X) indicates whether equipment is qualified to “E-field into equipment” (paragraph 19.3.2) tests (E) or not (X).

Category C_

Equipment intended primarily for operation in systems where interference-free operation is required and where severe coupling occurs due to long wire runs or minimum wire separation is identified as Category C_.

Category CC: Equipment is installed on aircraft whose primary power is constant frequency (e.g. 400 Hz) or DC

Category CN: Equipment is installed on aircraft whose primary power is variable over a narrow frequency range (e.g. 350 Hz – 650 Hz)

Category CW: Equipment is installed on aircraft whose primary power is variable over a wide frequency range (e.g. 350 Hz – 800 Hz)

Category Z_

Equipment intended primarily for operation in systems where interference-free operation is required is identified as Category Z_.

Category ZC: Equipment is installed on aircraft whose primary power is constant frequency (e.g. 400 Hz) or DC

Category ZN: Equipment is installed on aircraft whose primary power is variable over a narrow frequency range (e.g. 350 Hz – 650 Hz)

Category ZW: Equipment is installed on aircraft whose primary power is variable over a wide frequency range (e.g. 350 Hz – 800 Hz)

Category A_

Equipment intended primarily for operation where interference-free operation is desirable is identified as Category A_.

Category AC: Equipment is installed on aircraft whose primary power is constant frequency (e.g. 400 Hz) or DC

Category AN: Equipment is installed on aircraft whose primary power is variable over a narrow frequency range (e.g. 350 Hz – 650 Hz)

Category AW: Equipment is installed on aircraft whose primary power is variable over a wide frequency range (e.g. 350 Hz – 800 Hz)

Category B_

Equipment intended primarily for operation in systems where interference would be controlled to a tolerable level is identified as Category B_.

Category BC: Equipment is installed on aircraft whose primary power is constant frequency (e.g. 400 Hz) or DC

Category BN: Equipment is installed on aircraft whose primary power is variable over a narrow frequency range (e.g. 350 Hz – 650 Hz)

Category BW: Equipment is installed on aircraft whose primary power is variable over a wide frequency range (e.g. 350 Hz – 800 Hz)

19.3 Test Procedures**19.3.1 Magnetic Fields Induced Into the Equipment**

Subject the equipment under test to an audio frequency magnetic field, generated by the current specified in Table 19-1, in a straight wire radiator located within 0.15 m of the periphery of the unit of equipment under test. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

During this test, the radiating wire shall be oriented with respect to each external surface of each unit to cause maximum interference. The length of the radiator shall extend a distance of at least 0.6 m (laterally) beyond each extremity of the unit under test. The leads applying current to the radiator shall be routed at least 0.6 m away from any part of the unit under test and from the radiator itself. All units of the equipment under test shall be individually tested. The magnetic field power source shall not be synchronized with the power source of the equipment supply. During this test, place the wire horizontally and sweep up the front face of the EUT, across the top and down the back face of the EUT. Turn the radiating wire or EUT 90 degrees and sweep up the left (or right) face of the EUT, across the top, and down the right (or left) face of the EUT. Additional

radiating wire/EUT orientations are permissible. The goal is to test all four sides and the top of the box. Sweep at a rate slower than the system response time.

19.3.2 Electric Fields Induced Into the Equipment

Subject the equipment under test to an audio frequency electric field generated by 170V rms in a straight wire radiator of 0.20 m length located within 0.01 m of the periphery of the unit of equipment under test. See Table 19-1 for applicable test frequencies and levels. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

During this test, the radiator shall be oriented with respect to each external surface of each unit to cause maximum interference. For setup see Fig. 19-2. The leads applying voltage to the radiator shall be routed at least 0.6 m away from any part of the unit under test and from the radiator itself. All units of the equipment under test shall be individually tested. The electric field power source shall not be synchronized with the power source of the equipment supply.

During this test, place the wire horizontally and sweep up the front face of the EUT, across the top and down the back face of the EUT. Turn the radiating wire or EUT 90 degrees and sweep up the left (or right) face of the EUT, across the top, and down the right (or left) face of the EUT. The goal is to test all four sides and the top of the box. Sweep at a rate slower than the system response time.

A resistor sized for personnel protection shall be installed in the radiator wire.

Note: The Electric Field test should be applied only to equipment which is intended for installation without external metallic containment, or which is covered by an enclosure made from non-conducting material.

19.3.3 Magnetic Fields Induced Into Interconnecting Cables

Subject the interconnecting wire bundle of the equipment under test to an audio frequency magnetic field as illustrated in Figure 19-3. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS when the field is of the value specified in Table 19-1.

During this test, all equipment interconnecting cables shall be installed in accordance with the applicable installation and interface control diagrams. Any inputs or outputs from or to other equipment(s) normally associated with the equipment under test shall be adequately simulated. The magnetic field power source is not to be synchronized with the power source of the equipment power supply. Frequency scan rates and dwell times shall be in accordance with section 19.3.6

19.3.4 Electric Fields Induced Into Interconnecting Cables

Subject the interconnecting wire bundle of the equipment under test to an audio frequency electric field as illustrated by Figure 19-4. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS when the field is of the value specified in Table 19-1.

During this test, all equipment interconnecting cables shall be in accordance with the applicable installation and interface control diagrams. Shielded or twisted wires shall be used only where specified by the equipment manufacturer. Any inputs or outputs from or to other equipment(s) normally associated with the equipment under test shall be adequately simulated. The electric field power source shall not be synchronized with the power source of the equipment power supply. Frequency scan rates and dwell times shall be in accordance with section 19.3.6.

Note: Spiral wrapping of the radiator wire around the wire bundle under test is required for this test. The radiator wire shall be spiral wrapped around the bundle under test using 3 spiral wraps per meter length of the bundle, along the entire length L, as defined in Figure 19-4

19.3.5 Spikes Induced Into Interconnecting Cables

During this test, all equipment interconnecting cables shall be in accordance with the applicable installation and interface control diagrams. Shielded or twisted wires shall be used only where specified by the equipment manufacturer. Any inputs or outputs from or to other equipment normally associated with the equipment under test shall be adequately simulated.

Subject the interconnecting wire bundle of the equipment under test to both positive and negative transient fields using the test setup shown in Figure 19-5. Table 19-1 defines the desired cable lengths for categories of section 19.2. The timer shown in Figure 19-5 shall be adjusted to yield a pulse repetition rate of eight to ten pulses each second. The waveform present at point A, Figure 19-5, should be similar to that described in Figure 19-6. For both positive and negative polarities of the transient, the pulsing for each polarity shall be maintained for a period of not less than two minutes or for a longer period of time if specified in the relevant equipment specification.

Note: Spiral wrapping of the radiator wire around the wire bundle under test is required for this test. The radiator wire shall be spiral wrapped around the bundle under test using 3 spiral wraps per meter length of the bundle, along the entire length L, as defined in Figure 19-5

After exposure, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS. Any requirement for performance of the equipment during application of the tests will be specified in the equipment performance standard.

The inductive switching transient generated when the contact opens should be very similar to the illustration in Figure 19-6, when monitored at point A on Figure 19-5. When the contact opens, the voltage at Point A drives from +28 V dc to large negative voltages in about two microseconds. (The capacitance, 250 to 3,000 picofarad typically, between windings of the coil is charged negatively during this time.) When the voltage reaches the ionizing potential, arc-over occurs at the contact and the voltage drives rapidly toward 28 V dc through the ionized path at the contact. The voltage at Point A

usually overshoots +28 V dc because of the wire inductance between Point A and the coil. At this time, the arc extinguishes and the cycle is repeated. In a typical case, the repetition period is 0.2 to 10 microseconds and the number of repetitions is often 5 to 1,000 before the energy of the inductive load ($E = 1/2 LI^2$) is dissipated.

19.3.6 Frequency Scan Rates

For test equipment that generate discrete frequencies, the minimum number of test frequencies shall be 30 frequencies per decade. The test frequencies shall be logarithmically spaced. As an example a formula which can be used to calculate these frequencies for 30 steps per decade in ascending order is:

$$f_{n+1} = f_n * 10^{(1/30)}$$

where f_n is a test frequency and $n = 1$ to m ,
 f_1 is the start frequency
 f_m is the end frequency
 $m = 1 + 30 * \log(f_m/f_1)$

The dwell time at each test frequency shall be at least 10 seconds, exclusive of test equipment settling time. If the last test step for f_{n+1} yields a frequency greater than f_m , round down to f_m .

For test equipment that generate a continuous frequency sweep, the minimum (i.e., fastest) sweep rate shall be equal to the number of discrete frequencies per decade (m) multiplied by the dwell time, i.e., 30 discrete frequencies per decade times 10 second dwell time equals 5 minutes.

Table 19-1 Applicability of Categories to Induced Signal Susceptibility

Paragraph	Test	Category ZC	Category AC	Category BC	Category CC
19.3.1	Magnetic Fields induced into the equipment	20 A rms at 400 Hz	20 A rms at 400 Hz	20 A rms at 400 Hz	20 A rms at 400 Hz
19.3.2	Electric Fields induced into the equipment	170 V rms at 400 Hz	170 V rms at 400 Hz	170 V rms at 400 Hz	170 V rms at 400 Hz
19.3.3	Magnetic fields induced into interconnecting cables	I _x L=30 A-m at 400 Hz reducing to 0.8 A-m at 15 kHz	I _x L=18 A-m from 380 to 420 Hz	Not Applicable	I _x L=120 A-m from 380 to 420 Hz and 60 A-m at 400 Hz reducing to 1.6 A-m at 15 kHz
19.3.4	Electric Fields induced into interconnecting cables	V _x L=1800 V-m from 380 to 420 Hz	V _x L=360 V-m from 380 to 420 Hz	Not Applicable	V _x L=5400 V-m from 380 to 420 Hz and 5400 V-m at 400 Hz reducing to 135 V-m at 15 kHz
19.3.5	Spikes induced into interconnecting cables	Figure 19-4 L=3.0 m	Figure 19-4 L=3.0 m	Figure 19-4 L=1.2 m	Figure 19-4 L=3.0 m

Paragraph	Test	Category ZN	Category AN	Category BN	Category CN
19.3.1	Magnetic Fields induced into the equipment	20 A rms at 350 Hz and 650 Hz	20 A rms at 350 Hz and 650 Hz	20 A rms at 350 Hz and 650 Hz	20 A rms at 350 Hz and 650 Hz
19.3.2	Electric Fields induced into the equipment	170 V rms at 400 Hz	170 V rms at 400 Hz	170 V rms at 400 Hz	170 V rms at 400 Hz
19.3.3	Magnetic fields induced into interconnecting cables	I _x L=30 A-m from 350 to 650 Hz and reducing to 0.8 A-m at 26 kHz	I _x L=18 A-m from 350 to 650 Hz	Not Applicable	I _x L=120 A-m from 350 to 650 Hz reducing to 1.6 A-m at 26 kHz
19.3.4	Electric Fields induced into interconnecting cables	V _x L=1800 V-m from 350 to 650 Hz	V _x L=360 V-m from 350 to 650 Hz	Not Applicable	V _x L=5400 V-m from 350 to 650 Hz reducing to 135 V-m at 26 kHz
19.3.5	Spikes induced into interconnecting cables	Figure 19-4 L=3.0 m	Figure 19-4 L=3.0 m	Figure 19-4 L=1.2 m	Figure 19-4 L=3.0 m

Table 19-1 **Applicability of Categories to Induced Signal Susceptibility (continued)**

Paragraph	Test	Category ZW	Category AW	Category BW	Category CW
19.3.1	Magnetic Fields induced into the equipment	20 A rms at 350 Hz and 800 Hz	20 A rms at 350 Hz and 800 Hz	20 A rms at 350 Hz and 800 Hz	20 A rms at 350 Hz and 800 Hz
19.3.2	Electric Fields induced into the equipment	170 V rms at 400 Hz	170 V rms at 400 Hz	170 V rms at 400 Hz	170 V rms at 400 Hz
19.3.3	Magnetic fields induced into interconnecting cables	I _x L=30 A-m from 350 to 800 Hz and reducing to 0.8 A-m at 32 kHz	I _x L=18 A-m from 350 to 800 Hz	Not Applicable	I _x L=120 A-m from 350 to 800 Hz reducing to 1.6 A-m at 32 kHz
19.3.4	Electric Fields induced into interconnecting cables	V _x L=1800 V-m from 350 to 800 Hz	V _x L=360 V-m from 350 to 800 Hz	Not Applicable	V _x L=5400 V-m from 350 to 800 Hz reducing to 135 V-m at 32 kHz
19.3.5	Spikes induced into interconnecting cables	Figure 19-4 L=3.0 m	Figure 19-4 L=3.0 m	Figure 19-4 L=1.2 m	Figure 19-4 L=3.0 m

Note: When the manufacturer's installation and interface control drawings or diagrams specify a fixed length cable less than 3.3 m, the coupled length (L) of the field source wire shall be reduced to maintain the 0.15 m minimum separation distance at each end. The test level may be adjusted downward in proportion to the ratio of the reduced coupling length to the specified coupling length ($L = 3.3 - (2 \times 0.15) = 3 \text{ m}$). For example, if the manufacturer specifies a maximum cable length of 1.8 m, then $L = 1.5 \text{ m}$. The adjusted level is then $(1.5/3.0) = 0.5$ times the voltage (V-m) or current (A-m) test limits shown above. This test is not required when the manufacturer's installation and interface control drawings or diagrams specify a fixed length cable less than 1.5 m (L less than 1.2 m).

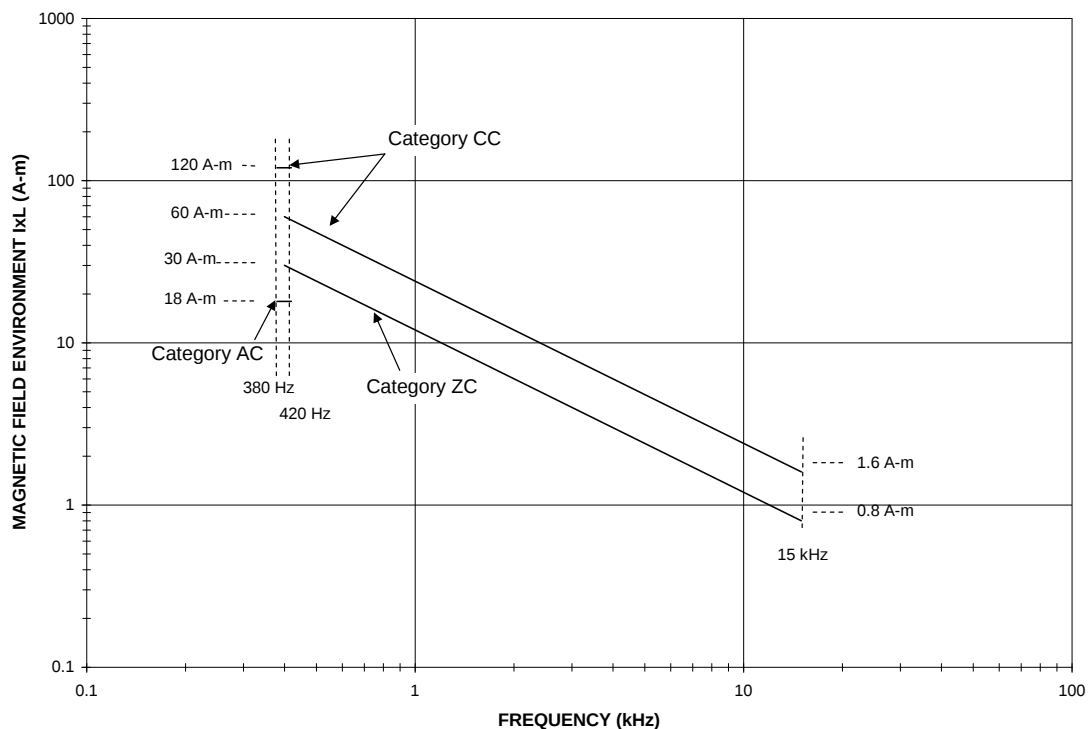


Figure 19-1(a) Audio Frequency Magnetic Field Susceptibility Test Levels – Constant Frequency

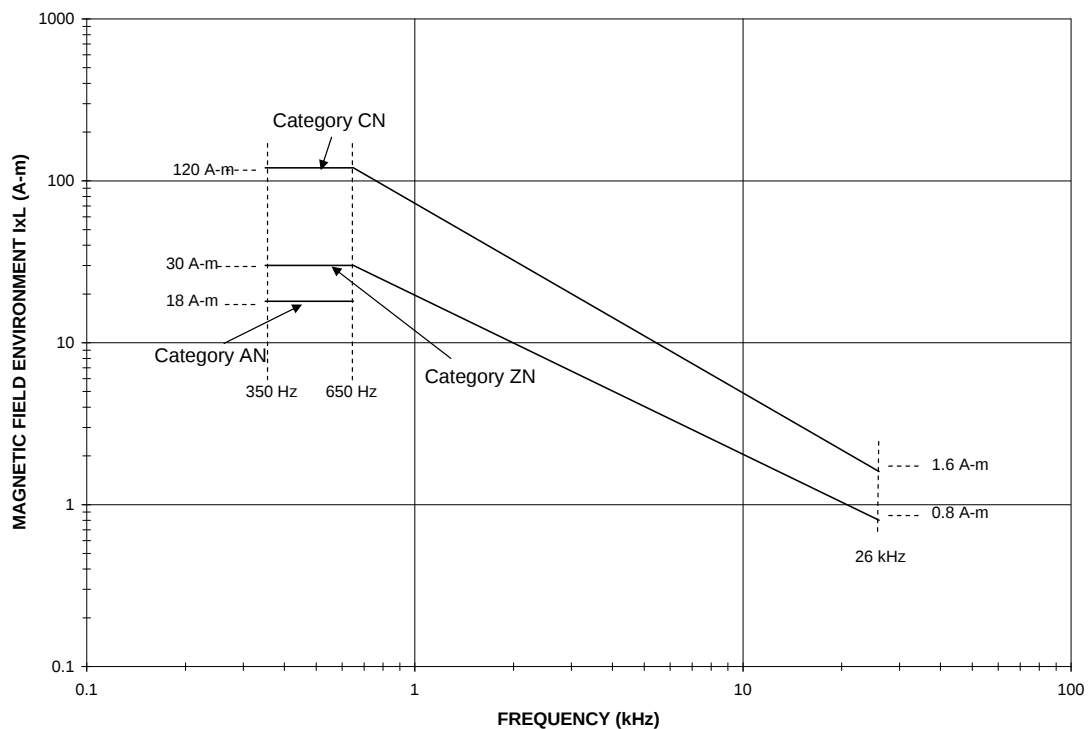


Figure 19-1(b) Audio Frequency Magnetic Field Susceptibility Test Levels – Narrow Frequency

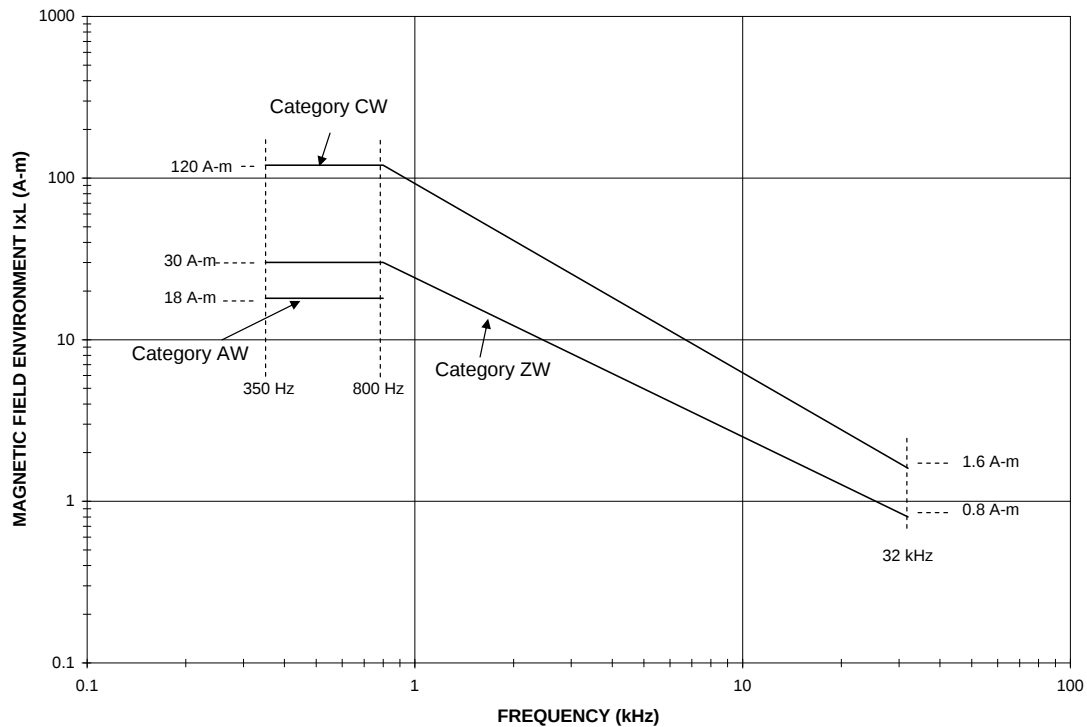


Figure 19-1(c) Audio Frequency Magnetic Field Susceptibility Test Levels – Wide Frequency

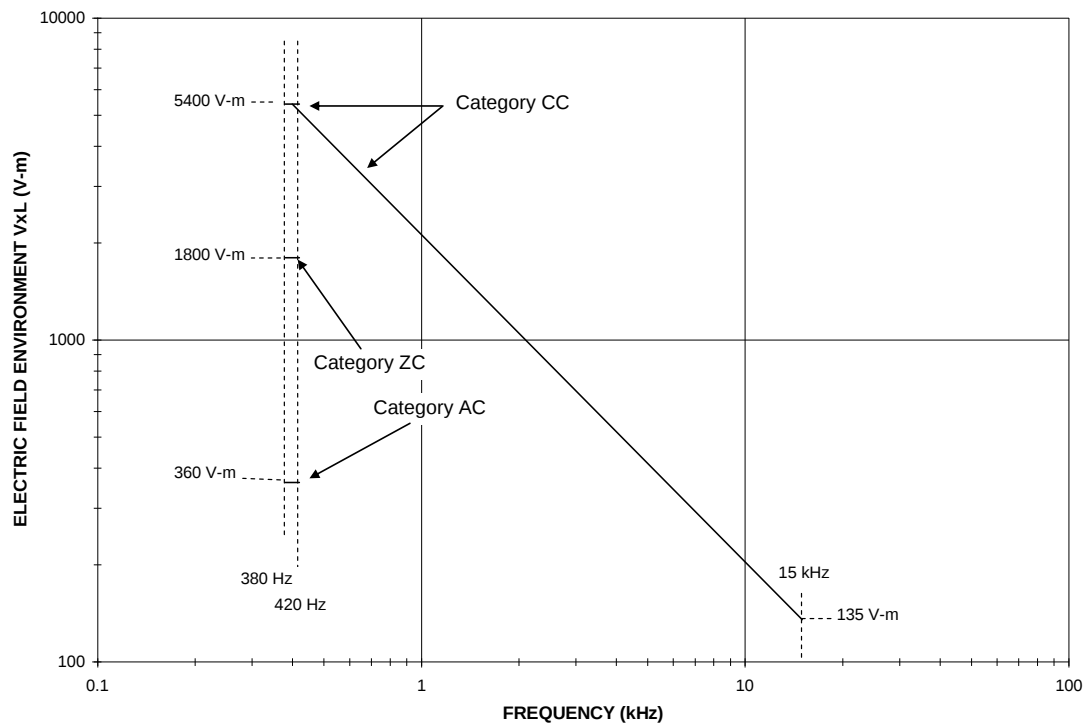


Figure 19-1(d) Audio Frequency Electric Field Susceptibility Test Levels – Constant Frequency

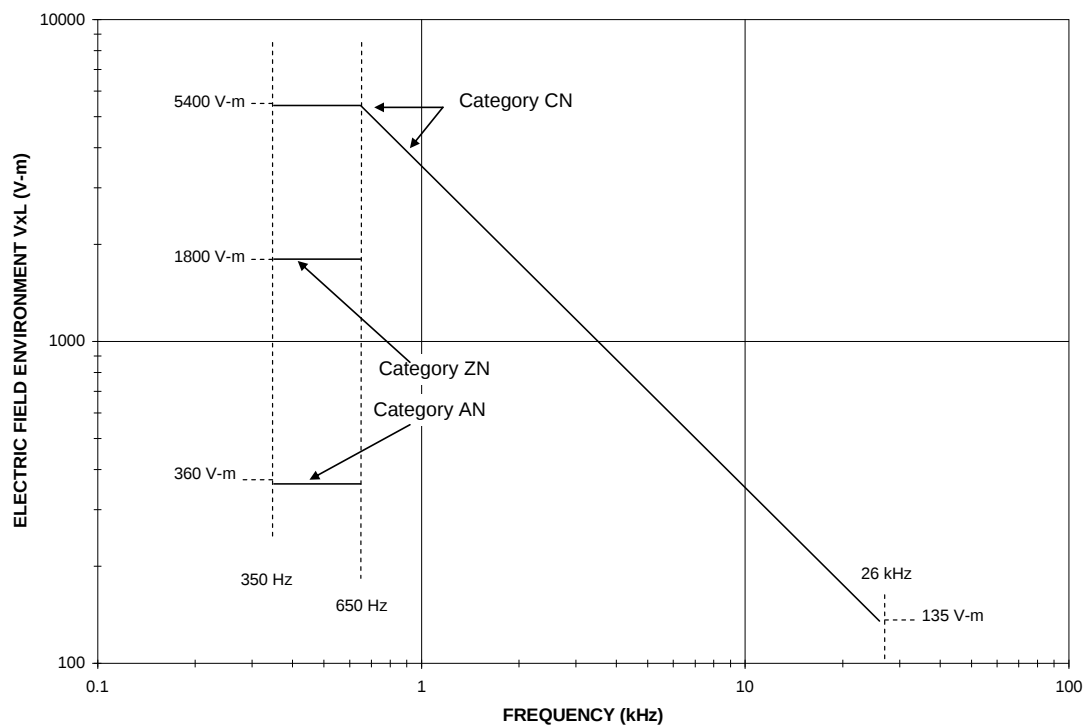


Figure 19-1(e) Audio Frequency Electric Field Susceptibility Test Levels – Narrow Frequency

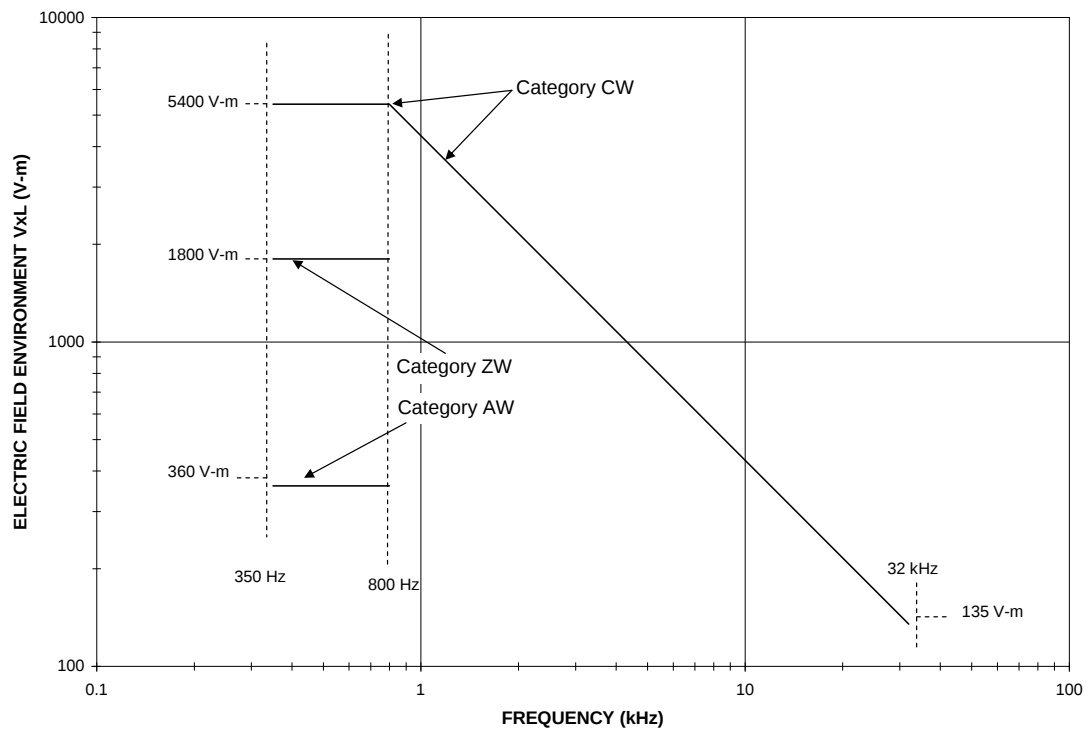


Figure 19-1(f) Audio Frequency Electric Field Susceptibility Test Levels – Wide Frequency

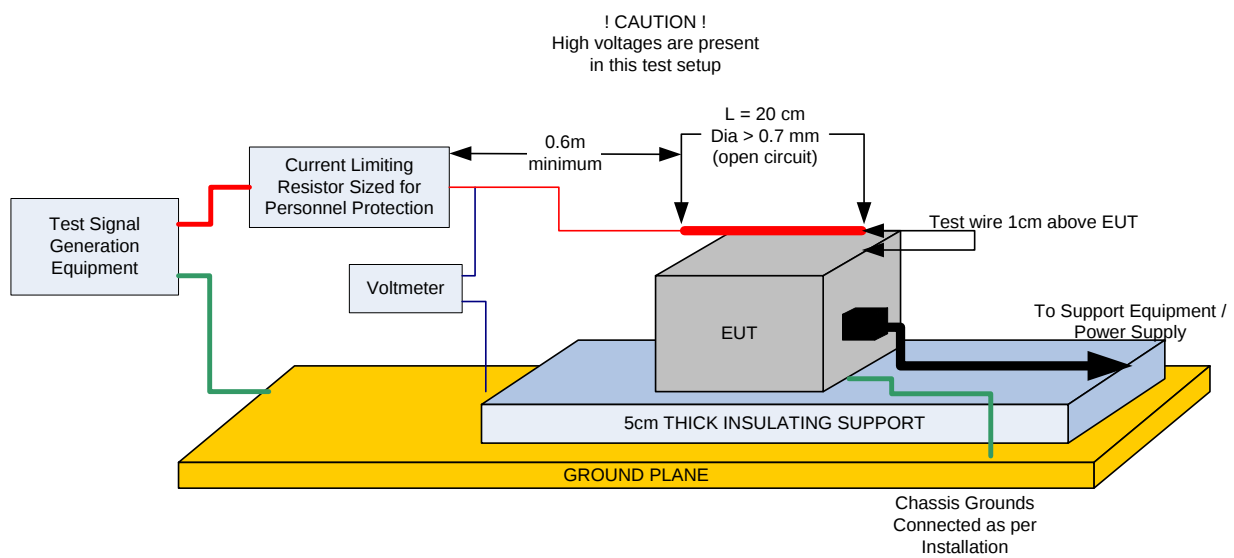
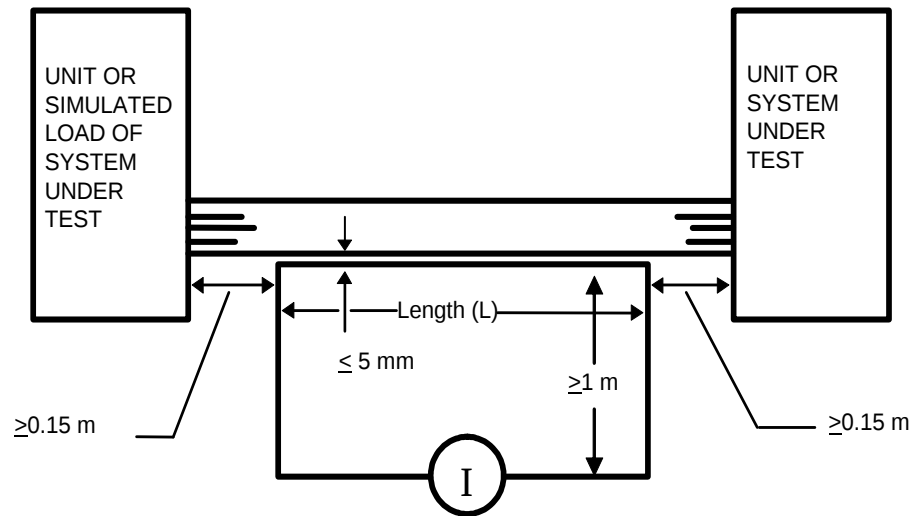


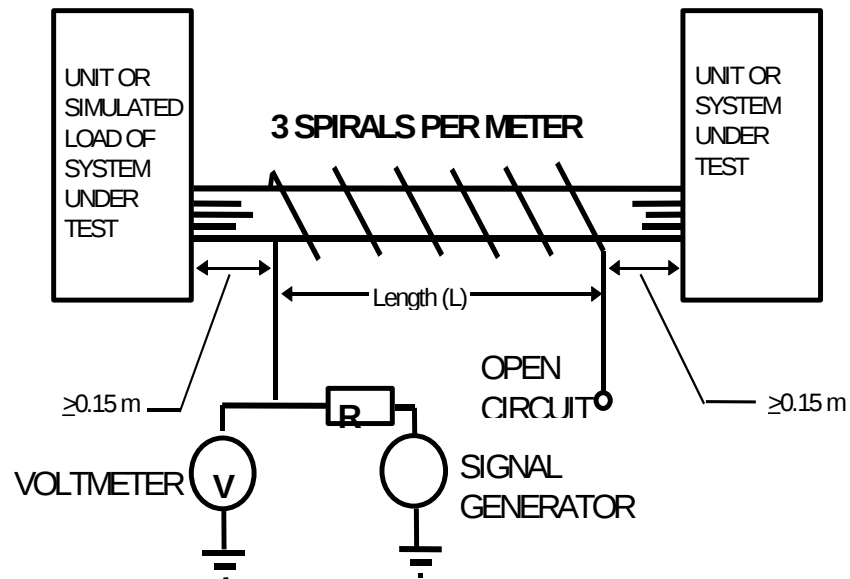
Figure 19-2 Audio Frequency Electric Field into Equipment Susceptibility Test Setup



Note 1: The interconnecting wire bundle shall be spaced a minimum of 50 mm above the ground plane.

Note 2: Magnetic Field Environment = Current (I) x Length (L)
(amperes rms x meters)

Figure 19-3 Audio Frequency Magnetic Field Susceptibility Test Setup

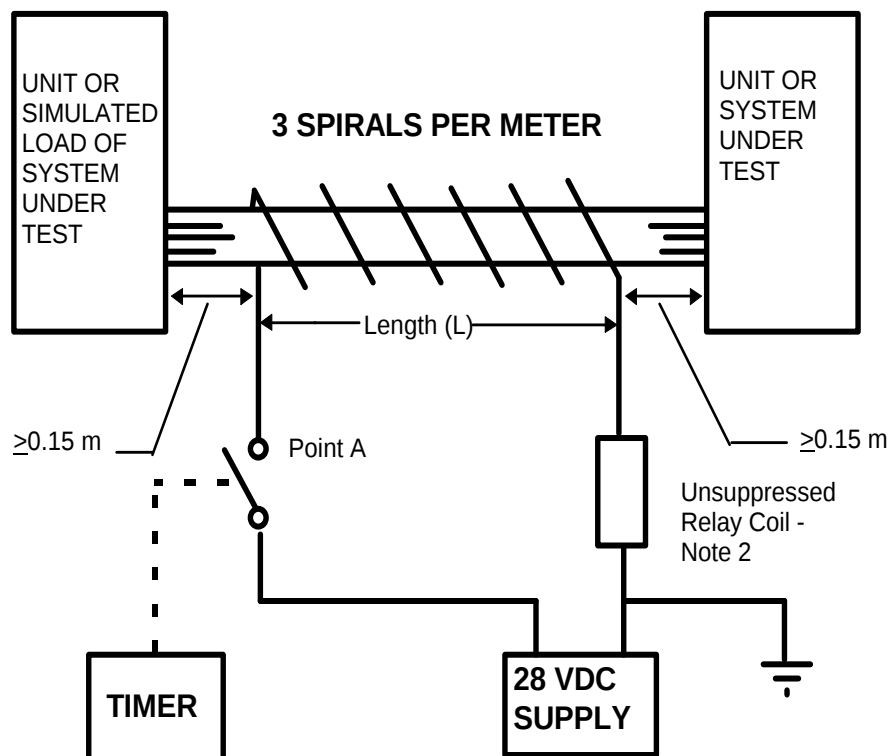


Note 1: The interconnecting wire bundle shall be spaced a minimum of 50 mm above the ground plane.

Note 2: Electric Field Environment = Voltage (V) x Length (L)
(volts rms x meters)

Note 3: R sized for personnel high voltage protection

Figure 19-4 Audio Frequency Electric Field Susceptibility Test Setup



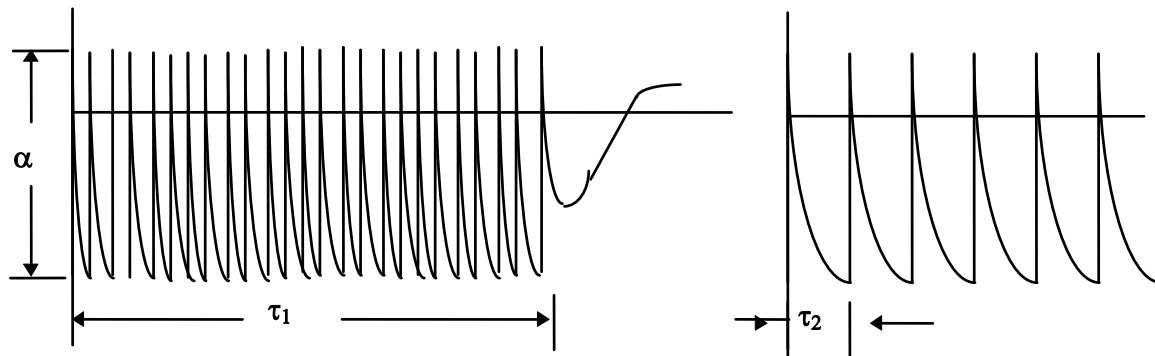
Note 1: The interconnecting wire bundle shall be spaced a minimum of 50 mm above the ground plane.

Note 2: The unsuppressed relay coil characteristics are as follows:

Voltage	=	28 volts dc
Current	=	160 mA
Resistance	=	175 ohms $\pm$ 10 %
Inductance	=	1.5 henries $\pm$ 10% in the energized position.

Note 3: 28 VDC supplied from ungrounded source with polarity reversing switch.

Figure 19-5 Interconnecting Cable Spike Test Setup



- α Amplitude ≥ 600 v p-p
 τ_1 Total Duration 50 to 1000 microseconds
 τ_2 Repetition Period 0.2 to 10 microseconds

Note: Voltage waveforms measured between Point A of Figure 19-4 and the ground plane. Inherently, the test will produce spikes of variable amplitude within a pulse. Some of the spikes may be less than the 600 V p-p level

Figure 19-6 Inductive Switching Transients

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 20

Radio Frequency Susceptibility (Radiated and Conducted)

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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20 Radio Frequency Susceptibility (Radiated and Conducted)

20.1 Purpose of the Test

These tests determine whether equipment will operate within performance specifications when the equipment and its interconnecting wiring are exposed to a level of RF modulated power, either by a radiated RF field or by injection probe induction onto the power lines and interface circuit wiring.

Two test procedures are used: 1) From 10 kHz to 400 MHz, the equipment under test (EUT) is subjected to RF signals coupled by means of injection probes into its cable bundles, and 2) for frequencies between 100 MHz and the upper frequency limit, the EUT is subjected to radiated RF fields. There is an intentional overlap of the tests from 100 to 400 MHz.

Radiated susceptibility tests from 100 MHz to 18 GHz may be conducted using methods and materials as described within Section 20.5 (Anechoic Chamber Method) or Section 20.6 (Reverberation Chamber Method). The choice of methods is at the discretion of the applicant.

Equipment with special signal, frequency, modulation or bandpass characteristics may require test variations as specified by the applicable performance standards.

The result of these tests can be used to:

- a) Determine equipment response to various RF threats such as HIRF, T-PEDs, and installed system's emissions, and to
- b) Permit categories to be assigned defining the conducted and radiated RF test levels of the equipment

These tests are sufficient to obtain environmental qualification for radio frequency susceptibility of the equipment. Additional tests may be necessary to certify the installation of systems in an aircraft dependent on the functions performed.

20.2 Equipment Categories

Categories designate the RF test levels and establish the EUT minimum RF immunity level. The categories may be given in the applicable equipment performance standard.

The category to be applied to a system or equipment frequently must be chosen before the internal RF environment of the aircraft is known. Further, many systems or equipments are designed with the intent that they will be installed in several different types of aircraft. Therefore, if a category is not identified in the equipment specification, the equipment manufacturer should design, test and qualify the equipment to the category consistent with expected location, exposure and use.

Category designation for equipment consists of two characters. Conducted susceptibility test levels are designated with the first category character. Radiated susceptibility test levels are designated with the second category character.

To aid the equipment manufacturer in selecting appropriate test limits for the equipment and its interconnecting wiring, categories have been defined below. The descriptions are for guidance only. Equipment location, anticipated exposure/location of interconnecting wiring, and aircraft size and construction determine the test level.

Categories B, D, F, G, L, M and O provide test levels which directly relate to the high intensity radiated field (HIRF) external field environments for systems with highest criticality as specified in the HIRF regulations.

Category R provides test levels for equipment when:

- a) Bench testing is allowed to meet the HIRF for systems with high criticality as specified in the HIRF regulations, and
- b) Showing backdoor Transmitting-Portable Electronic Device (T-PED) tolerance.

Category S provides a minimum test level where aircraft effects from the external electromagnetic environment are minor and where interference free operation on the aircraft is desirable but not required. This category may also be representative of the internal EMI environment from aircraft equipment.

Category T provides test levels for equipment when bench testing is allowed to meet the HIRF for systems with moderate criticality as specified in the HIRF regulations. This category may also be representative of the internal EMI environment from aircraft equipment.

Categories W and Y provide test levels for:

- a) Bench testing supporting compliance to HIRF Special Conditions, and
- b) Showing backdoor T-PED tolerance

Category Q indicates tests conducted at test limits or with modulations other than those specified in these procedures.

20.3

General Test Requirements

a. Equipment Under Test

The EUT shall be set up on a ground plane (test bench) and configured in accordance with the following criteria:

- (1) Ground Plane – A copper, brass or aluminum ground plane, at least 0.25 mm thick for copper and aluminum, 0.5 mm thick for brass, 2.5 m² or more in area with a minimum depth (front to back) of 0.75 m shall be used. When a shielded enclosure is employed, the ground plane shall be bonded to the shielded enclosure at intervals no greater than one meter and at both ends of the ground plane. It is recommended that the DC bonding resistance should be 2.5 milliohms or less.
- (2) Shock and Vibration Isolators – If specified by the equipment manufacturer, the EUT shall be secured to mounting bases incorporating shock or vibration isolators. The bonding straps furnished with the mounting bases shall be connected to the ground plane. Bonding straps shall not be used in the test setup, when they are not incorporated in the mounting bases.
- (3) Electrical Bonding – Only the provisions included in the EUT design or installation instructions, e.g., bonding of enclosure, mounting base and ground plane, shall be used for bonding.

The electrical bonding of equipment, connectors, and wire bundles shall be representative of aircraft installations as specified by the applicable installation and interface control drawings or diagrams. The test report shall describe the bonding methods employed.

- (4) External Ground Terminal – When an external terminal is available for a ground connection on the EUT, the terminal shall be connected to the ground plane to ensure safe operating conditions during the test. The length of the connection defined in the installation instructions shall be used; if a length is not defined, use approximately 30 cm of a representative type of wire.
- (5) Interconnecting Wiring/Cables – All EUT interconnecting wiring (e.g., shielded wires, twisted wires, etc.), cable bundles and RF transmission lines shall be in accordance with the applicable installation and interface control drawings or diagrams.

Cables shall be bundled in a manner similar to that of aircraft installations and the lowest point of the cable bundle supported at a minimum height of 50 mm above the ground plane unless greater heights have been specified as more representative of the aircraft installation (and recorded in the test report). The supporting material must be non-absorptive, non-conductive, and non-reflective. For complex cable bundle configurations, all cable bundles and interconnected loads should be kept separated from each other as much as practical to minimize coupling effects between cables. Interconnect cabling may be routed in the same direction as the power leads along the edge of the test bench and should be kept separated from each other as much as practical to minimize coupling and shadowing effects between cables, unless otherwise specified in the aircraft installation specification.

Unless otherwise specified, cable lengths shall be at least 3.3 m. When the length of an interconnecting cable bundle is greater than the test bench, the cable bundle should be arranged with the excess length zigzagged at the back of the test bench approximately 50 mm above the ground plane. At least one meter of cable from the EUT must be 10 cm from the front of the test bench and parallel to the front of the test bench as shown in [Figure 20-2](#) and [Figure 20-9](#). For complex cable bundles, the edge of the first separated bundle shall be 10 cm from the edge. The cable bends at the EUT shall not extend past the edge of the ground plane. The EUT may be moved away from the edge to accommodate the minimum cable bend radius. Antenna spacing to EUT shall be maintained as shown in [Figure 20-2](#).

Some special installations may require very long cable bundle lengths which cannot be accommodated on the test bench. Therefore, the recommended maximum length of the interconnecting cable bundles for these tests is 15 m. The exception to this limitation is where cable bundle lengths are matched or specified to a particular length for phase match or similar reasons.

Any inputs or outputs from, or to, other equipment or loads associated with the EUT shall be provided by an actual in-service type of device or shall be simulated taking into account the line-to-line and line-to-ground frequency dependent impedances.

- (6) Power Leads – For cable bundle tests, power and return leads normally bundled with the control/signal leads shall remain in the cable bundle and only be separated from the bundle as close as possible to the cable bundle exiting the test area. These leads shall then be connected to Line Impedance Stabilization Networks (LISNs).

When the actual aircraft cable bundle configuration is unknown or when power and/or return leads are normally routed separately from the control/signal leads, the power and return leads should be broken out of the cable bundle near the connector of the EUT and run separately to the LISNs. Under these conditions, the length of the leads to the LISNs shall be 1.0m +/-10cm unless otherwise specified in the applicable equipment specification. Power leads may be routed in the same direction as the interconnect cabling along the edge of the test bench and should be kept separated from each other as much as practical to minimize coupling and shadowing effects between cables, unless otherwise specified in the aircraft installation specification.

When the return lead is a local ground (less than 1 meter length), this lead may be grounded directly to the test bench, in accordance with the applicable installation and interface control drawings or diagrams.

- (7) Dummy Antennas or Loads – For the purpose of this test, antenna cables may be terminated in a load equal to the cable characteristic impedance, or a

dummy antenna. The dummy antenna, if used, shall be shielded and be designed to have electrical characteristics closely simulating the in-service antenna. It shall also contain electrical components normally used in the antenna, such as filters, crystal diodes, synchros and motors.

b. Shielded Enclosure and Test Equipment

Enclosures, test equipment and instruments shall be set up and operated in accordance with the following criteria:

- (1) Bonding Test Equipment – Test equipment shall be bonded and grounded to minimize ground loops and ensure personnel safety.
- (2) Line Impedance Stabilization Network (LISN) – An LISN shall be inserted in each EUT primary power line. Power return lines locally grounded in the aircraft installation do not require an LISN. The LISN case shall be bonded to the ground plane. When LISNs with self resonances above 10 kHz are used (such as standard 5 μ H LISNs), a 10 microfarad capacitor shall be inserted between each LISN power input terminal and the ground plane for the entire test. The RF measurement port of the LISN shall be terminated into 50 ohms for all tests. The input impedance characteristic is shown in Figure 20-1.
- (3) Antenna Orientation and Positioning in Shielded Enclosures – Dipole, biconical or horn antennas shall be centered 0.3 m above the level of the ground plane and parallel to the ground plane as shown in Figure 20-2. If the transmitting antenna being used is a pyramidal horn, such as a standard gain horn or similar type radiator, as the dimensions of the antenna become small and the frequency of interest becomes higher, it is permissible to move the antenna closer to the EUT than the one meter shown in Figure 20-2. This can only be done when the far field boundary of the antenna is within this one meter distance. The position of the transmit antenna relative to the EUT must remain equal to or greater than the far field boundary of the transmitting horn antenna. It is also allowable to move the antenna farther than one meter from the EUT.

If the transmit antenna far field boundary is less than or equal to one meter it is also allowable to move the antenna farther than one meter from the EUT. The appropriate field strength at the EUT must be maintained. Moving the transmit antenna farther away will increase the illuminated area, decreasing the number of antenna placements required for large EUT configurations.

Note: The far field boundary of the antenna is calculated by the following equation:

$$x = \frac{2 * D^2}{\lambda}$$

where x = far field boundary distance in meters
 D = largest dimension of the transmitting aperture in meters, and
 λ = wavelength of the frequency of interest in meters.

Note : Far-field boundaries less than one meter from the antenna are unusual and may exist only for frequencies above approximately 8 GHz when using quite small antennas..

When the beam width of the antenna does not totally cover the system under test, multiple area scans shall be performed. However, it is required that each EUT within the system and at least one-half wavelength of wiring of that EUT shall be exposed in its entirety during the test. In shielded enclosure tests, the antenna shall be at least 0.3 m away from the shielded enclosure wall or absorber. Alternate antennas may be used provided the required field strengths are obtained.

Note: The above does not apply if the alternate radiated susceptibility test procedure of Section 20.6 is used.

- (4) Injection Probes – Probes shall have the necessary power and range capabilities. Injection probe insertion loss limits are shown in [Figure 20-3](#). A suggested test setup for measuring the injection probe insertion loss is shown in [Figure 20-4](#). Support and center the probe in the fixture.
- (5) Shielded Enclosure – Shield room effects on equipment and test setup shall be minimized to the greatest extent possible. RF absorber material shall be used during radiated testing inside a shielded enclosure to reduce reflections of electromagnetic energy and to improve accuracy and repeatability. As a minimum, the RF absorber shall be placed above, behind, and on both sides of the EUT, and behind the radiating antenna as shown in [Figure 20-2](#). Minimum performance of the material shall be as specified in [Table 20-1](#). The manufacturer's specification of their RF absorber material (basic material only, not installed) is acceptable.

Note: The above is not applicable if the alternate radiated susceptibility test procedure of Section 20.6 is used.

Fiber-optic interfaces may be provided for test equipment and sensors to help give susceptibility-free monitoring. The design and protection of test aids, monitors and load stimulation units should ensure appropriate simulation, isolation and immunity of test equipment interface circuits to RF currents.

- (6) Amplifier System Harmonics - Distortion of sinusoidal susceptibility signals caused by non-linear effects in power amplifiers can lead to erroneous interpretation of results. When distortion is present, the EUT may actually respond to a harmonic of the intended susceptibility frequency, where the required limit may be lower. When frequency selective receivers are used to monitor the injected level, distortion itself does not prevent a valid susceptibility signal level from being verified at the intended frequency. However, harmonic levels should be checked when susceptibility is present to determine if they are influencing the results. When broadband sensors are being used, distortion can result in the sensor incorrectly displaying the required signal level at the intended frequency. In this case, distortion needs to be controlled such that correct levels are measured.

c. Amplitude Measurement

The amplitudes associated with the categories are based on the peak of the rms envelope over the complete modulation period as shown in [Figure 20-5](#). Amplitude measurements shall be made in a manner which clearly establishes the peak amplitude of the modulated waveform. This instrument must have a fast enough time response to respond to signal amplitude variations, particularly for Section 20.6. A spectrum analyzer may be used. The detection, resolution, and video bandwidths of the measuring instrument must be greater than the modulating frequency. The measurement bandwidth shall be increased until the amplitude of the measured signal does not change by more than 1 dB for a factor of three increases in bandwidth. This bandwidth setting shall then be used for the test. At the proper setting, the individual modulation sidebands will not be resolved. For the Conducted Susceptibility test of paragraph 20.4, an oscilloscope may be used as the amplitude measuring device. The oscilloscope must have an analog bandwidth compatible with the upper frequency limit of the test and must have the appropriate 50 ohm terminations

d. Test Frequency Exclusions

RF receiving equipment may show sensitivity to in-band receive frequencies during susceptibility testing. This sensitivity is normal for devices that are required to be sensitive according to the receiver MOPS. This sensitivity is therefore normal and such frequencies may need to be excluded or levels at these frequencies reduced during testing.

Unless otherwise specified by the applicable receiver minimum performance standard, the following exclusion band shall apply for radio receivers. The band of frequencies from ten percent below the lowest operating frequency in the band to ten percent above the highest operating frequency shall be tested to Category S levels. Required receiver performance shall be stated in the test procedure and report, or in the specific receiver performance standard. The frequencies from one percent below the radio receiver tuned frequency through one percent above the tuned frequency shall be tested to Category S for damage assessment only.

This test is not intended to evaluate the normal MOPS RF performance characteristics of the receivers, nor is the test intended to evaluate receiver performance in the presence of any interfering signal induced or coupled into the receiver's RF input port(s). Other responses due to power line and/or control/signal line coupling, or direct coupling through the receiver's enclosure shall be evaluated and pass/fail criteria determined based on the specific receiver specifications or performance requirements.

e. Frequency Scan Rates

Sweep or step rates shall be selected with consideration of equipment under test (EUT) response time, EUT susceptibility bandwidths, and monitoring test equipment response time. The scan rate selected shall be justified by this criteria, and documented in the test report.

For test equipment that generates discrete frequencies, the minimum number of test frequencies shall be 100 frequencies per decade above 100 kHz, and 10 frequencies per decade below 100 kHz. The test frequencies shall be logarithmically spaced. As an example (above 100 kHz), a formula which can be used to calculate these frequencies in ascending order is:

$$f_{n+1} = f_n * 10^{(1/100)}$$

where f_n is a test frequency and $n = 1$ to m ,
 f_1 is the start frequency, and
 f_m is the end frequency
 $m = 1 + 100 * \log(f_m / f_1)$ rounded up to the nearest integer

If the last test step for f_{n+1} yields a frequency greater than f_m , then set the last frequency to f_m .

The dwell time at each test frequency shall be at least one second, exclusive of test equipment settling time. Additional dwell time at each test frequency may be necessary to allow the EUT to be exercised in appropriate operating modes and to allow for the “off time” during low frequency modulation. At least two full cycles of modulation must be applied. For example, if the applied modulation is a 1 Hz square wave modulation (SW), the dwell time shall not be less than two seconds. The dwell time selected shall be justified based on EUT and test equipment response time, as well as applied modulation, and documented in the test report. This requirement is not applicable to section 20.6.

For test equipment that generate a continuous frequency sweep, the minimum (fastest) sweep rate shall be equal to the number of discrete frequencies per decade multiplied by the dwell time, i.e., 100 discrete frequencies per decade times 1 second dwell time equals 100 seconds per decade sweep rate. The fastest sweep rate shall be used only when the EUT and associated test equipment are capable of fully responding to the test stimulus. Typically, slower rates are required, as described above.

Note: Additional test frequencies shall be included for known equipment response frequencies, such as image frequencies ($nLO \pm IF$; where n includes all integers from 2 through 10, LO is the local oscillator

frequency, and IF is the intermediate frequency), IFs, clock frequencies, etc.

f. Data Required in Test Report

The test report shall include, (either directly or by reference), the following test setup and data items:

1. Cable Configuration(s) – The length of each cable bundle, types of wiring, shielding and shield terminations (including individual as well as overall shields), and the wiring diagrams of the test harness.
2. Test Set ups – Schematic of block diagrams or photographs of each test setup including layout of cable bundles, placement of injection and measurement probes and the EUT bonding
3. EUT Operating Mode(s) – The mode(s) of operation used during tests
4. Load(s) – A description of all loads, either actual or simulated. Simulated loads shall identify the extent of impedance simulation both line-to-line and line-to-case
5. Pass/Fail Criteria – A description of the pass/fail criteria.
6. Test Results

20.4

Conducted Susceptibility (CS) Test

a. Applicability/Intent

Subject the EUT and interconnecting cables or circuits to the appropriate category of Figure 20-6, while monitoring the induced cable bundle current. All cable bundles and appropriate branches that connect the EUT to other equipment or interfacing units in the aircraft system are subject to this test.

For all categories, the induced current on the wiring bundle under test is used to establish the test level, with the forward power to the injection probe to be the test limit.

Interconnecting wiring can be tested as a whole or as individual wires. Simultaneous injection with separate probes on several bundles may be used, and may be required for equipment with built-in redundancy. Power return leads or ground leads that are grounded directly to the test bench, as required in Section 20.3.a.(6), shall not be included in the bundle under test and are not required to be tested.

b. Probe Calibration

Set up the signal generator, power amplifier, directional coupler, attenuator, amplitude measurement instruments, and install the injection probe in the calibration fixture per [Figure 20-7](#). Support and center the probe in the fixture. Set the signal generator to 10 kHz, unmodulated. Increase the amplifier power fed through the directional coupler to the injection probe at 10 kHz until the current or power measured on amplitude measurement instrument #1 indicates the resulting current or power into the calibration fixture for the selected category of [Figure 20-6](#).

CAUTION: RF fields due to re-radiation from the calibration jig may be hazardous. Observe appropriate RF exposure limits.

Record the signal generator/power amplifier forward power to the injection probe on amplitude measurement instrument #2.

Scan the frequency band (unmodulated) while recording forward power on amplitude measurement instrument #2 and maintaining power amplitudes on amplitude measurement instrument #1 per Table 20-2 and/or Figure 20-6 from 10 kHz to 400 MHz for the proper probe. The forward power plot will be used to establish the test limit for the conducted susceptibility test requirement, as defined in 20.4.d.

The VSWR of the attenuators and loads shall be less than 1.2:1. The calibration jig VSWR without the probe installed shall not exceed the values of [Figure 20-8](#).

c. CS Test Setup

Set up the EUT, wiring, associated interface circuitry, and test equipment per [Figure 20-9](#). For test setups with shielded cables which include in-line connectors (e.g. aircraft installation stanchion or bulkhead disconnects), the in-line shield terminations must be lifted from ground to allow the CS current to flow on the shield for a minimum distance of 3m. Install the induced current monitor probe five centimeters from the EUT. If the EUT connector plus backshell length exceeds five centimeters, the probe shall be placed as close to the connector backshell as possible and the position noted. Support and center the probe. Install the injection probe five centimeters from the face of the monitor probe.

d. CS Test Procedure

Establish proper probe locations, software installation, modes of operation and stability of the EUT, test equipment and all monitoring circuits and loads.

CAUTION: RF fields due to re-radiation from the cable bundle under test can be hazardous. Observe appropriate RF exposure limits.

Set the signal generator to 10 kHz. Adjust and control the forward power to achieve the induced current on the cable bundle for the selected category level of Table 20-2, and/or Figure 20-6. When necessary, limit the forward power to not more than 6 dB above the calibration value determined during the probe calibration procedure in Section 20.4.b. Scan the frequency range at the proper bundle current level without exceeding the forward power limit. Record the induced current and applied forward power in the test report.

Dwell at internal modulation, data, clock frequencies, and other critical frequencies as required. When modulation is applied, ensure that the peak amplitude complies with the definitions of Section 20.3.c and Figure 20-5.

While scanning, evaluate EUT operation and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

e. CS Modulations

Apply both CW and square wave modulation. Modulate the RF carrier with 1 kHz square wave modulation with at least 90 percent depth.

Also consider applying other modulations associated with the EUT, such as clock, data, IF, internal processing or modulation frequencies. Especially consider any possible low frequency response characteristic of the EUT, for example, a flight control equipment's response to 1 Hz modulation in the 2 to 30 MHz HF range. As an option, tests can be run using only the modulation to which the EUT is most susceptible.

20.5 Radiated Susceptibility (RS) Test – Anechoic Chamber Method

a. Applicability/Intent

Subject the EUT and interconnecting cables to the appropriate category of RF fields for Table 20-3 and Figure 20-10.

b. Radiated Field Calibration

Perform a field calibration in the test chamber prior to placement of the EUT within that test chamber, to establish the correct field strength for the category selected.

CAUTION: RF fields can be hazardous. Observe appropriate RF exposure limits.

Perform the reference CW field calibration using a three-axis omnidirectional electric field antenna (isotropic probe) or equivalent with appropriate frequency response. The isotropic probe should be centered at approximately the same location as the placement of the EUT on the groundplane, 30 cm above the groundplane. Alternatively, the probe may be placed in a different position within the shielded

enclosure with the probe 30 cm above a similar ground plane, and with a similar absorber configuration. Radiate the isotropic probe, unmodulated, at the desired test frequency. Adjust the forward power to the transmit antenna to achieve the total field strength indication from the isotropic probe for the category selected. Total field strength is defined as the root sum squared (RSS) of the magnitude of the rectangular components. Record the forward power and use this power setting during the EUT radiated field test. Repeat this calibration over the required frequency range.

Note: This calibration must be accomplished prior to each test. It is not allowed to use the calibration data from one test to the next unless the test equipment has not been disconnected since the performance of the calibration. If any equipment has been disconnected (including coax, cables, antennas, wave guide, etc.) that is within the calibration loop, then it is required to verify that the calibration is still valid prior to conducting/continuing the test.

The forward power necessary to produce the desired category field strength at the isotropic probe with a CW signal becomes the reference forward power. Square wave (SW) and pulse modulated (PM) signals should be developed in a manner which produces the same forward power into the transmitting antenna as the calibration level. (Note that all levels are "peak rms" as defined in Section 20.3.c and [Figure 20-5](#)). Appropriate scale factors may be used if the reference CW calibration was performed at a different level than the desired square wave or pulse category field strength.

Forward power to the transmit antenna shall be monitored and recorded using an amplitude measurement instrument that meets the requirements in Section 20.3.c.

Both horizontal and vertical polarization field exposures are required. Circularly polarized transmit antennas are not permitted.

c. RS Test Set-up

Set up the EUT, wiring, associated interface circuitry and test equipment per [Figure 20-2](#).

Signal generators, amplifiers, antennas and probes shall maintain required RF field levels to properly illuminate the EUT and interconnecting wiring. Position and aim antennas to establish the RF field strengths at the EUT and interconnecting wiring. Define the 3 dB points of the radiated field using antenna beam width specifications, or by mapping the area in which the EUT is to be placed. The beam widths of the antennas used in the test should be stated in the test report. When the 3 dB beam width of the antenna does not totally cover the EUT and wiring, perform multiple area scans. Directly expose apertures in the EUT (e.g., displays, CRTs, connectors) to the transmitting antenna, which may require additional LRU or antenna orientations.

Vertical and horizontal transmit antenna orientations are required. Any face that was not exposed to the transmitting antenna has to be justified in the test form. The antenna distance used for calibration must be the same distance used for testing.

d. RS Test Procedure

Establish appropriate antenna and isotropic probe locations, software installation, modes of operation and stability of the EUT, test equipment and all monitoring circuits and loads. The isotropic probe is used as verification that the transmit path is functioning correctly. The applied field strength is derived from the forward power calibration of Section 20.5.b.

CAUTION: RF fields can be hazardous. Observe appropriate RF exposure limits.

Use the forward power settings determined from the radiated field calibration. When modulation is applied, ensure that the peak amplitude complies with the definitions of Section 20.3.c and Figure 20-5.

Scan the frequency range to the upper frequency limit using appropriate modulations. Dwell at internal modulation, data and clock frequencies, as required.

While scanning, evaluate the EUT operation and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

e. RS Modulations

For category R use the following levels and modulations:

From 100 MHz to 400 MHz use 20 V/m CW. Also use 20 V/m with 1 kHz square wave modulation with at least 90% depth.

From 400 MHz to 8 GHz, use 150 V/m pulse modulated at 4% duty cycle and 1 kHz pulse repetition frequency. Switch the signal on and off at a 1 Hz rate and 50% duty cycle to simulate the effect of rotational radars.

For categories S, T, W and Y, use the following modulations:

From 100 MHz to the upper frequency limit in Figure 20-10, use CW as well as 1 kHz square wave modulation with at least 90% depth. Also consider using additional modulations associated with the EUT such as clock, data, IF, internal processing, or modulation frequencies.

For categories B, D, F, G, & L use the following modulations:

When testing to the appropriate SW/CW levels from Table 20-3, use CW and a 1 kHz square wave modulation with at least 90% depth from 100 MHz to 18 GHz. Also consider using additional modulations associated with the EUT such as clock, data, IF, internal processing or modulation frequencies.

From 400 MHz to 4 GHz, use the appropriate pulse modulated (PM) test level with a 4 μ s pulse width (or greater) and 1 kHz pulse repetition frequency. From 4 GHz to 18 GHz, use the appropriate pulse modulated (PM) test level with a 1 μ s pulse width (or greater) and 1 kHz pulse repetition frequency. Especially consider switching the signal on and off at a 1 Hz rate and 50% duty cycle for an EUT which may have a low frequency response (e.g. flight control equipment)

For all categories: Above 1 GHz it is permissible to use SW modulation at 1.42 times the CW field strength requirement to satisfy both CW and SW requirements simultaneously (e.g. 142 V/m SW, 50% duty cycle to qualify 100 V/m CW and SW).

20.6 Radiated Susceptibility (RS) Test; Alternate Procedure – Reverberation Chamber - Method**20.6.1 Applicability/Intent**

Subject the EUT and interconnecting cables to the appropriate category of RF fields for Table 20-3 and/or Figure 20-10.

20.6.2 Procedure

This procedure defines an alternative radiated susceptibility test using a Reverberation Chamber. In a reverberation chamber test, the field at the EUT is varied in polarization and illumination angle by the stirring rotation of a metal tuner. At each frequency, one full rotation of the metal tuner is required. Apply predetermined power level to generate the required calculated field (within some degree of statistical certainty) to the EUT.

The procedure consists of the following basic steps:

a. Prior to the fitting of the test bench and/or EUT:

A performance based field uniformity calibration technique shall be performed to demonstrate adequate reverberation chamber performance following initial construction or after major modification to the reverberation chamber. The chamber calibration technique is carried out to demonstrate the chamber meets the field uniformity requirements as defined in this procedure. In addition, it is important to determine the lowest useable frequency (LUF) of the reverberation chamber employed. The described chamber field uniformity calibration is to be carried out over a test/working volume, which includes the location of the conductive test bench within the reverberation chamber. The chamber calibration must be performed using mode tuned (stepped tuner rotation) operation of the reverberation chamber. Chamber calibration using mode stirred (continuous tuner rotation) operation is not allowed because of E-Field probe limitations. The field uniformity measurement should be carried out with the conductive test bench removed from the reverberation chamber. The test is to be carried out at 9 locations for 3 individual axes (x,y,z) at each test location, i.e. 27 measurement points in total (Section 20.6.3.1). The field within the chamber is considered uniform if the standard deviation is within 3dB above 400 MHz, and sloping linearly (on a semi-log plot) from 6 to 3 dB from 100 MHz to 400 MHz.

b. Prior to the start of the test with the test bench and EUT installed in the chamber:

The typical test setup should be as shown in [Figure 20-13](#). The equipment layout shall be representative of the actual installation as specified in Section 20.3.a.(5). The EUT shall be located inside the working volume as defined in Section 20.6.3.1.

The transmit and receive antennas shall be the same antennas used in Section 20.6.3.1.

The receive antenna shall be within the working volume (see section 20.6.3.1). Establish software installation, modes of operation and stability of the EUT, test equipment, and all monitoring circuits and loads.

- i. Inject a CW signal into the chamber with a transmit antenna. Monitor the maximum forward power over one tuner rotation with the use of a directional coupler and applicable measurement device, e.g., rf power probe or spectrum analyzer.
- ii. Monitor the receive power on a receive antenna placed inside the working volume of the chamber over one tuner rotation. If multiple tuners are used, the measurement time shall correspond to the slowest tuner speed.
- iii. Using the following equation, determine the peak field strength inside the chamber.

$$E_{\max} = \sqrt{\frac{377 * 8 * \pi * (P_{rcv \max})}{\lambda^2}}$$

Where:

$E_{\max}$ = the maximum field strength inside the chamber (V/m)

$P_{rcv \max}$ = the maximum recorded power measured over one tuner rotation(W)

λ = the wavelength of the test frequency (m)

- iv. Record both the maximum forward power and the maximum field strength over one full tuner rotation.
- v. Move to the next test frequency

- vi. Repeat steps (i) through (v).

Note: The forward power and receive power obtained from this calibration will now maintain a linear relationship (e.g., if forward power is increased by 6 dB, the receive power will increase by 6 dB.) This relationship also applies to pulse testing.

c. The EUT test:

- i. Using the information from the chamber calibration procedure (20.6.3.1), calculate the target forward power with the following equation:

$$P_{Target} = 20 * \log\left(\frac{E_{desired}}{E_{max}}\right) + P_{Fwd}$$

Where:

P_{Target} = Target forward power (dBm)

$E_{desired}$ = Desired field strength inside the chamber (V/m)

E_{max} = Field strength measured in section 20.6.2.b (V/m)

P_{Fwd} = Forward power measured in section 20.6.2.b (dBm)

- ii. Rotate the tuner at a rate of 4 revolutions per minute below 1 GHz and 2 revolutions per minute above 1 GHz, or slower while continuously applying power for one tuner revolution. For gated modulations (e.g the 1Hz gating of Cat R) the tuner rotation rate must be reduced by the gating duty cycle (e.g. a 50% gating duty cycle will reduce the tuner rate to 2 rpm). Stopping the tuner rotation is permissible as long as the power is continuously applied and the tuner speed between stops does not exceed the 4 revolutions per minute.
- iii. At the applicable test frequency, drive the forward power to P_{Target} , verify the forward power reading with a directional coupler and applicable measurement device by measuring the peak forward power over one full rotation

- iv. Ensure the receive antenna is connected to an appropriate monitoring device to monitor the power on the receive antenna throughout one full revolution. If the monitoring equipment comes out of the noise floor, no further action concerning the receive antenna need be taken. If power is not detected on the antenna, further investigation is warranted to ensure that the field is actually present in the reverberation chamber. Without verification that there is power getting to the receive antenna, the test is not considered valid.
- v. Move to the next test frequency
- vi. Repeat steps (i) through (v)

Step through the frequency range to the upper frequency limit using the appropriate modulations. Modulate the carrier as specified in Section 20.5. When modulation is applied, ensure that the peak amplitude complies with the definitions of Figure 20-5. Test at internal modulation, data and clock frequencies, as required.

At each frequency, evaluate EUT operation and DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS during the entire tuner rotation.

20.6.3 Calibration: Chamber Field Uniformity and Loading Validation

As an initial guide to chamber performance and input power requirements, perform a “one-time” empty chamber calibration (no EUT) using the procedures of 20.6.3.1. It is suggested the empty chamber calibration be carried out on an annual basis or after major modification to the reverberation chamber.

For normal operation the lowest test frequency (f_s) is 100 MHz, and field uniformity is demonstrated over the first decade of operation. If a start frequency other than 100 MHz is chosen, for example a small chamber used to generate high field strengths, the chamber field uniformity must still be verified over the first decade of operation. The frequency at which a chamber can be used to conduct measurements is the frequency at which the chamber meets the field uniformity requirements in Figure 20-11.

20.6.3.1 Field Uniformity Validation

- i. Clear the working volume (i.e. remove test bench) and place the receive antenna at a location within the working volume of the chamber as outlined in the notes of Figure 20-12. Set the amplitude measurement instrument to monitor the receive antenna on the correct frequency.
- ii. Place the E-field probe at a location on the perimeter of the chamber working volume as shown in Figure 20-12.

- iii. Beginning at the lowest test frequency (f_s), adjust the RF source to inject an appropriate input power, P_{Input} , into the transmit antenna. The transmit antenna shall not directly illuminate the working volume or the receive antennas and probes. Directing the source antenna into one corner of the chamber is an optimum configuration. The frequency shall be in band for both the transmit and receive antennas which shall be linearly polarized antennas.
- iv. Step the tuner through 360° in discrete steps (mode-tuned operation) and at each step care must be taken to ensure that the dwell time is sufficiently long enough that the amplitude measurement instrumentation and E-field probes have time to respond properly. Each step must be an equal angular movement. The limitation on the minimum number of tuner positions is that the field uniformity requirements must still be met. The limit on the maximum number of positions is that each step should vary the field pattern in the chamber enough to be statistically significant eg an independent sample.
- v. Record the maximum field strength ($E_{Max\ x,y,z}$) for each axis of the E-field probe, the maximum total vectorial field strength (E_{Total}), and the average value of the input power (P_{Input}) over the tuner rotation.

Note: *The value for input power, $P_{Input-empty}$, is the forward power averaged over the tuner rotation and the maximum total E-field is the root sum squared (RSS) of the magnitude of the rectangular components at one position of the tuner. All calibrations are antenna specific. Changing antennas may void calibrations. All power measurements are relative to the antenna terminals. This procedure provides generic values of antenna efficiency for log periodic and horn antennas. Other types of antennas may be used, provided their efficiency is known. Antenna efficiency is the ratio of the power accepted by an antenna to the total power at the measurement location. The measurement requires a spherical scan of the antenna. The typical gain and antenna factor provided by antenna manufacturers cannot be used to derive the antenna efficiency.*

- vi. Repeat the above procedure in log spaced frequency steps as outlined in Table 20-4 until frequency is at least $10f_s$.
- vii. Repeat for each of the nine probe locations shown in Figure 20-12 and for nine receive antenna locations (one of which must be at the center of the working volume) until $10f_s$.

Note: The receive antenna should be moved to a new location within the working volume of the chamber for each change in probe location. The antenna should also be placed in a new orientation relative to the chamber axis at each location (at least 20° in each axis). For reference purposes x = chamber length (longest dimension), y = chamber width,

and z = chamber height. The probe does not necessarily need to be oriented along the chamber axes during calibration.

Care should be take to ensure that the proper separation distance between the antenna and probe are maintained. Each location should be at least 0.75 meter (or $\lambda/4$ at the lowest test frequency) from any previous location. If the receive antenna is to be mounted in a fixed position during routine testing, it is suggested that one of the locations should be the intended permanent location of the receive antenna.

- ix. Using the data from step (v.), normalize each of the maximum E-field probe measurements to the square root of the average input power:

$$\tilde{E}_{x,y,z} = \frac{E_{Maxx,y,z}}{\sqrt{P_{Input-empty}}}$$

where

$E_{Maxx,y,z}$ = maximum measurement from each probe axis (i.e. 27 measurements below $10f_s$),

$\tilde{E}_{x,y,z}$ = normalized maximum measurement from each probe axis, and

$P_{Input - empty}$ = average input power to the chamber during the tuner rotation at which $E_{Maxx,y,z}$ was recorded.

AND

$$\tilde{E}_{Total} = \frac{E_{MaxTotal}}{\sqrt{P_{Input-empty}}}$$

where

$E_{MaxTotal}$ = maximum measurement of the total E-field from the probe at each location (i.e. 9 measurements below $10f_s$),

$\tilde{E}_{Total}$ = normalized maximum total measurement from each probe location,

P_{Input} = average input power to the chamber during the tuner rotation at which $E_{MaxTotal}$ was recorded.

- x. For each calibration frequency, calculate the average of the normalized maximum for each axis of the E-field probe measurements, $\langle \vec{E}_{x,y,z} \rangle$:

For each frequency below $10f_s$:

$$\langle \vec{E}_x \rangle_9 = (\sum \vec{E}_x) / 9$$

$$\langle \vec{E}_y \rangle_9 = (\sum \vec{E}_y) / 9$$

$$\langle \vec{E}_z \rangle_9 = (\sum \vec{E}_z) / 9$$

Also calculate the average of the normalized maximum of all the E-field probe measurements giving equal weight to each axis (i.e. each rectangular component), $\langle \vec{E} \rangle_{27}$:

$$\langle \vec{E} \rangle_{27} = (\sum \vec{E}_{x,y,z}) / 27$$

Note: $\langle \rangle$ denotes arithmetic mean, i.e.

$$\langle \vec{E} \rangle_{27} = (\sum \vec{E}_{x,y,z}) / 27$$

represents the sum of the 27 rectangular E-field maximums (normalized) divided by the number of measurements.

- xi. For each frequency below $10f_s$ determine if the chamber meets the field uniformity requirements as follows:

- (a) The field uniformity is specified as a standard deviation from the mean value of the maximum values obtained at each of the nine locations during one rotation of the tuner. The standard deviation is calculated using data from each probe axis independently (e.g. σ_x) and the total data set (e.g. σ_{27}). (**CAUTION:** DO NOT confuse “total data set” with the total E-field).

The standard deviation is given by:

$$\sigma = \alpha * \sqrt{\frac{\sum (\vec{E}_i - \langle \vec{E} \rangle)^2}{n-1}}$$

where

n = number of measurements,

$\vec{E}_i$ = individual normalized E-field measurement,

$\langle \vec{E} \rangle$ = arithmetic mean of the normalized E-field measurements,
 and
 α = 1.06 for $n \leq 20$ and 1 for $n > 20$.

For example, for the x vector:

$$\sigma_x = 1.06 * \sqrt{\frac{\sum (\vec{E}_{ix} - \langle \vec{E}_x \rangle_9)^2}{9-1}}$$

where

$\vec{E}_{ix}$ = individual measurement of x vector, and
 $\langle \vec{E}_x \rangle$ = arithmetic mean of normalized $E_{Max\ x}$ vectors from all 9 measurement locations.

And for all vectors:

$$\sigma_{27} = \sqrt{\frac{\sum (\vec{E}_{ix,y,z} - \langle \vec{E} \rangle_{27})^2}{27-1}}$$

where

$\vec{E}_{ix,y,z}$ = individual measurements of all vectors (x, y and z),
 $\langle \vec{E} \rangle_{27}$ = arithmetic mean of normalized $E_{Max\ x,y,z}$ vectors from all 27 measurements, and
 σ_{27} = standard deviation of all vectors (x, y, and z).

The standard deviation is expressed in terms of dB relative to the mean:

$$\sigma(dB) = 20 * \log \left(\frac{\sigma + \langle \vec{E} \rangle}{\langle \vec{E} \rangle} \right)$$

- (b) The chamber passes the field uniformity requirements if the standard deviation of the individual field components (e.g. $\sigma_{x,y,z}$) does not exceed the standard deviation specified in [Figure 20-11](#) for more than two frequencies per octave, and the standard deviation for all vectors (i.e. σ_{27}) does not exceed the specified standard deviation. If the chamber fails to meet the uniformity requirement it may not be possible for the chamber to operate at the desired lower frequency. If the margin by which the chamber fails to meet the uniformity requirement is small, it may be possible to obtain the desired uniformity by:

- 1) increasing the number of samples (i.e. tuner steps) by 10% to 50%,
- 2) normalizing the data to the net chamber input power ($P_{Net} = P_{Input} - P_{Reflected}$), or
- 3) reducing the size of the working volume.

If the chamber exceeds the required field uniformity, the number of samples required may be reduced, but not below a minimum of twelve tuner steps. This offers the ability to optimize each chamber for the minimum number of samples and therefore minimize test time.

Note: If the tuner fails to provide the required uniformity then the uniformity may be improved by increasing the number of tuners, making the tuner(s) larger, or lowering the Q by adding absorber. The chamber characteristics (size, construction method, wall materials) should also be evaluated to determine if the chamber is likely to pass the requirement. Chambers with no more than 60 to 100 modes at the lowest test frequency or very high Qs (such as those encountered in all welded aluminum chambers) are likely to encounter difficulty in meeting the required uniformity.

IMPORTANT: Once a chamber has been modified (e.g. absorber added, etc.) or the calibration procedure modified (e.g. changed number of tuner steps, etc.) to obtain a desired characteristic, that configuration and/or procedure must remain the same for the duration of the test for that calibration to remain valid.

20.6.3.2 Chamber Time Constant Calculation

Calculate the chamber calibration factor (*CCF*) for each frequency using the following equation:

$$CCF = \left\langle \frac{P_{AveRec}}{P_{AveInput}} \right\rangle$$

where

CCF = the normalized average received power over one tuner rotation with the EUT and supporting equipment present,

P_{AveRec} = the average received power over one tuner rotation with the EUT and supporting equipment present

$P_{AveInput}$ = the forward power averaged over one tuner rotation with the EUT and supporting equipment present

In order to assure that the time response of the chamber is fast enough to accommodate pulsed waveform testing, determination of the chamber time constant shall be accomplished using the following procedure:

- i. Using the *CCF*, calculate the quality factor, *Q*, for every test frequency above 400 MHz using:

$$Q = \left(\frac{16\pi^2 V}{\eta_{Tx} \eta_{Rx} \lambda^3} \right) (CCF)$$

where

η_{Tx}, η_{Rx} = the antenna efficiency factors for the transmit and receive antenna respectively and can conservatively be assumed to be 0.75 for a log periodic antenna and 0.9 for a horn antenna,

V = the chamber volume (m^3),

λ = the free space wavelength (m) at the specific frequency, and

CCF = the chamber calibration factor.

- ii. Calculate the chamber time constant, τ , for every test frequency above 400 MHz using:

$$\tau = \frac{Q}{2\pi f}$$

where

τ = time constant (sec)
 Q = the value calculated in step (i.) above, and
 f = the test frequency (Hz).

The chamber time constant must be added to any required pulse width during pulse modulation testing (e.g., if the chamber time constant is 6 microseconds and the required pulse width is 4 microseconds, it is required to perform the test at a 10 microsecond pulse width during pulse modulated testing).

Note: It is permissible to add the required pulse width to the empty chamber time constant in lieu of the pulse width above.

TABLE 20-1 RF ABSORPTION AT NORMAL INCIDENCE

Frequency	Minimum Absorption
100 to 250 MHz	6 dB
Above 250 MHz	10 dB

TABLE 20-2 CONDUCTED SUSCEPTIBILITY TEST LEVELS VERSUS CATEGORY

Frequency (MHz)	Category Levels (mA)						
	M	O	R	S	T	W	Y
0.01	0.6	3	0.6	0.03	0.15	3	6
0.5	30	150	30	1.5	7.5	150	300
1	70	250	30	1.5	7.5	150	300
30	70	250	30	1.5	7.5	150	300
40	*	*	30	1.5	7.5	150	300
100	*	*	*	*	*	*	300
400	32	50	3	0.15	0.75	32	100

* Interpolate per figure 20-6

TABLE 20-3 RADIATED SUSCEPTIBILITY TEST LEVELS VERSUS CATEGORY

Environment	Cat B (V/m)		Cat D (V/m)		Cat F (V/m)		Cat G (V/m)		Cat L (V/m)		Cat R (V/m)		Cat S (V/m)	Cat T (V/m)	Cat W (V/m)	Cat Y (V/m)
Frequency		PM		PM	SW/ CW	PM	SW/ CW	PM		PM	SW/ CW	PM	SW/ CW	SW/ CW	SW/ CW	SW/ CW
100-200 MHz	20		25		50		100		200		20		1	5	100	200
200-400 MHz	20		25		50		100		200		20		1	5	100	200
400-700 MHz	20	150	20	175	25	350	50	700	200	730		150	1	5	100	200
700 MHz-1 GHz	20	150	25	175	50	350	100	700	240	1400		150	1	5	100	200
1-2 GHz	25	250	50	500	100	1000	200	2000	250	5000		150	1	5	100	200
2-4 GHz	25	375	50	750	100	1500	200	3000	490	6000		150		5	100	200
4-6 GHz	25	375	50	750	100	1500	200	3000	400	7200		150		5	100	200
6-8 GHz	25	150	50	250	100	500	200	1000	200	1100		150		5	100	200
8-12 GHz	38	375	75	750	150	1500	300	3000	330	5000					100	200
12-18 GHz	25	250	50	500	100	1000	200	2000	330	2000					100	200

TABLE 20-4 REVERBERATION CHAMBER TEST CRITERION

Frequency Range ¹	Number of frequencies ² required to establish field uniformity
f_s to $4f_s$	50/decade
$4f_s$ to $8f_s$	50/decade
Above $8f_s$	20/decade

1 f_s is the start frequency

2 log spaced

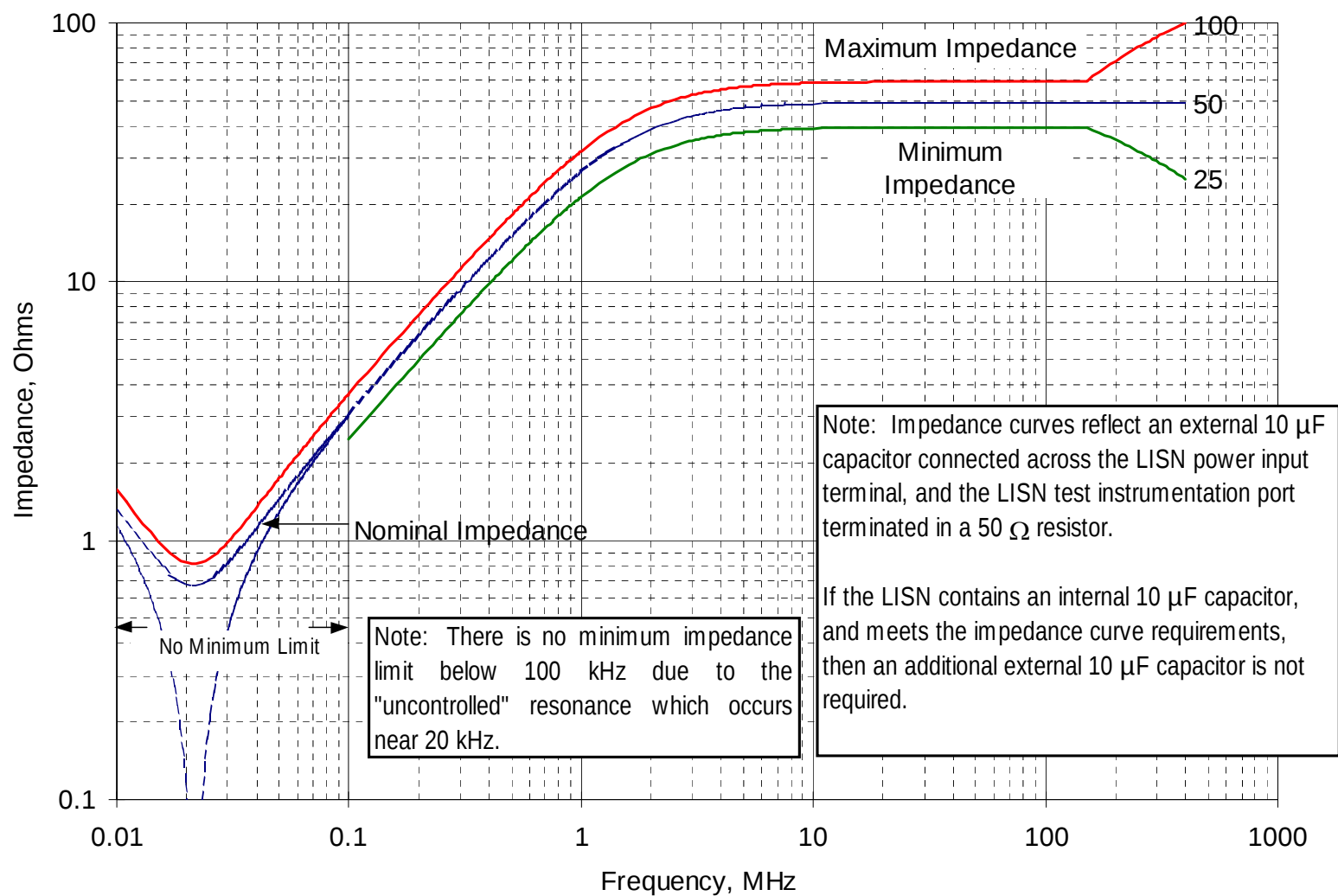


FIGURE 20-1 LISN IMPEDANCE STABILIZATION NETWORK INPUT IMPEDANCE

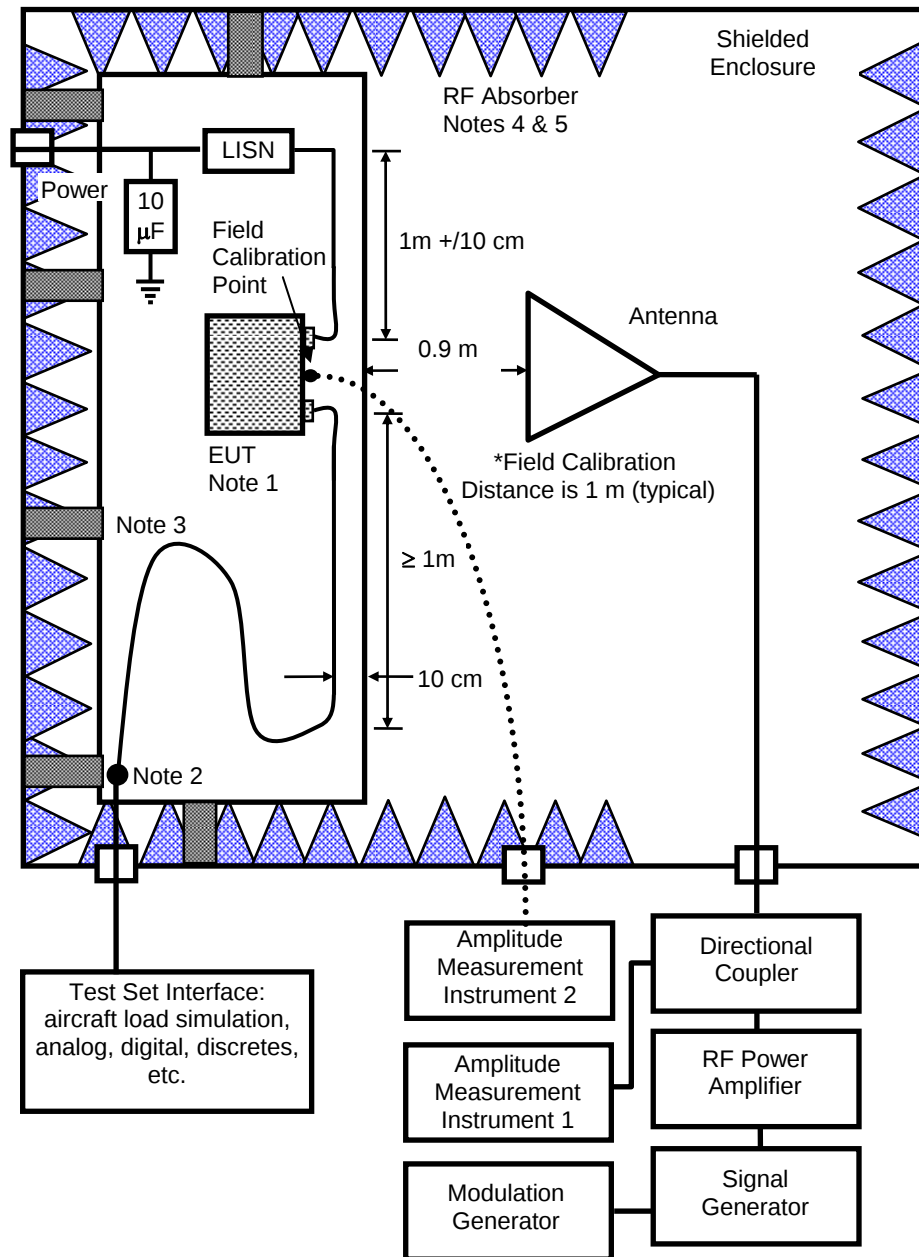


FIGURE 20-2 RADIATED SUSCEPTIBILITY TEST SETUP

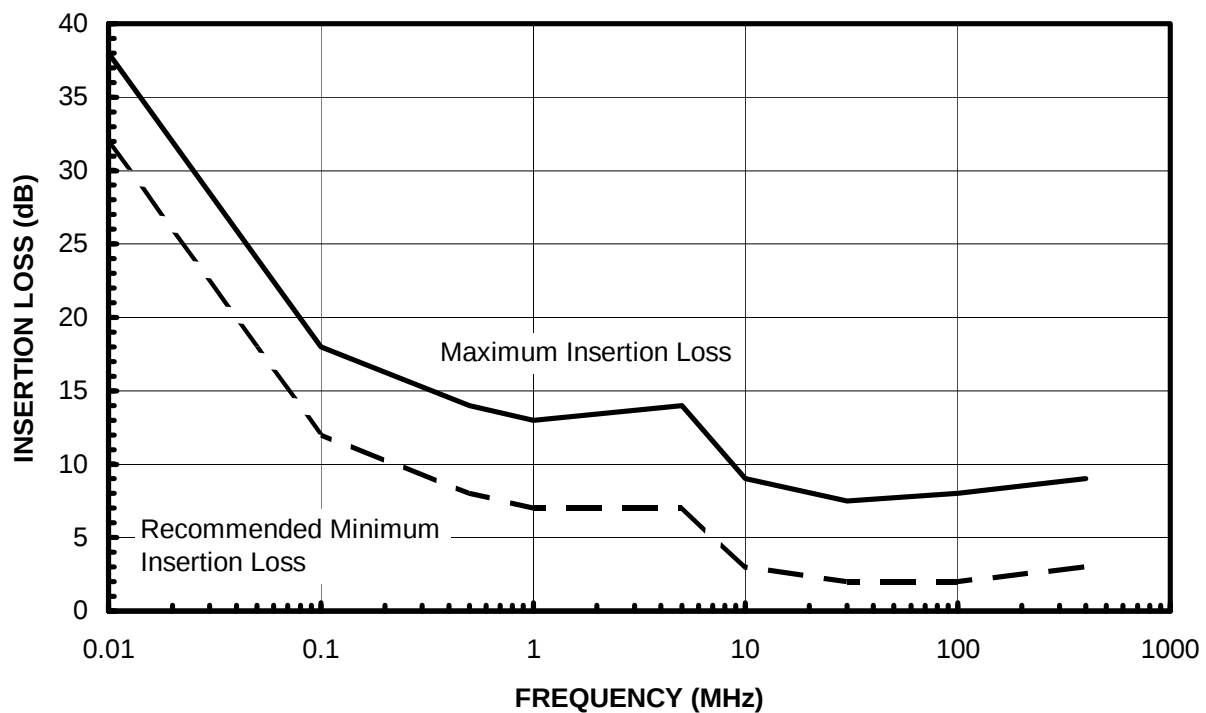


FIGURE 20-3 INJECTION PROBE INSERTION LOSS LIMITS

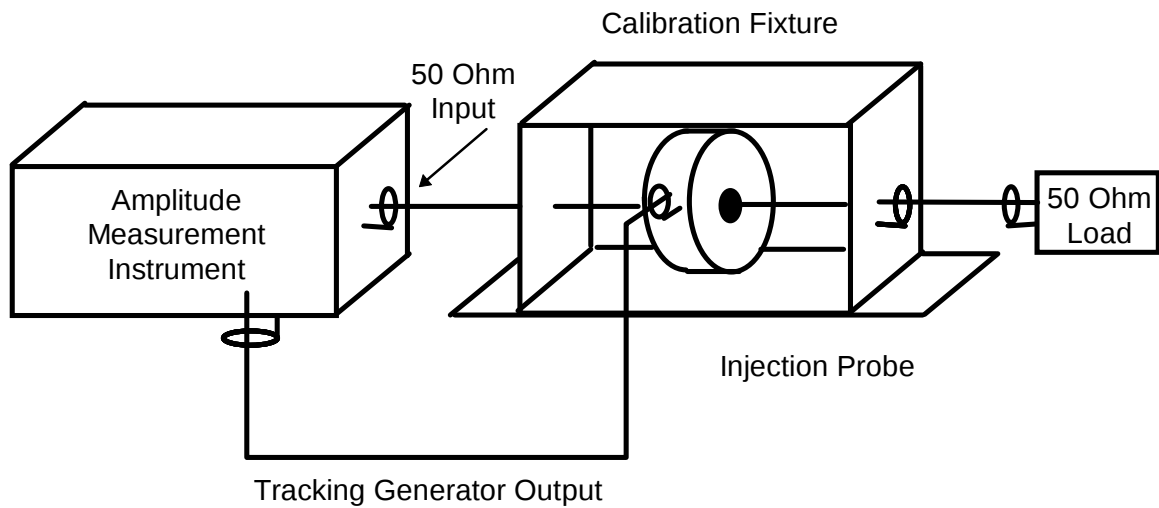


FIGURE 20-4 INJECTION PROBE INSERTION LOSS TEST SETUP

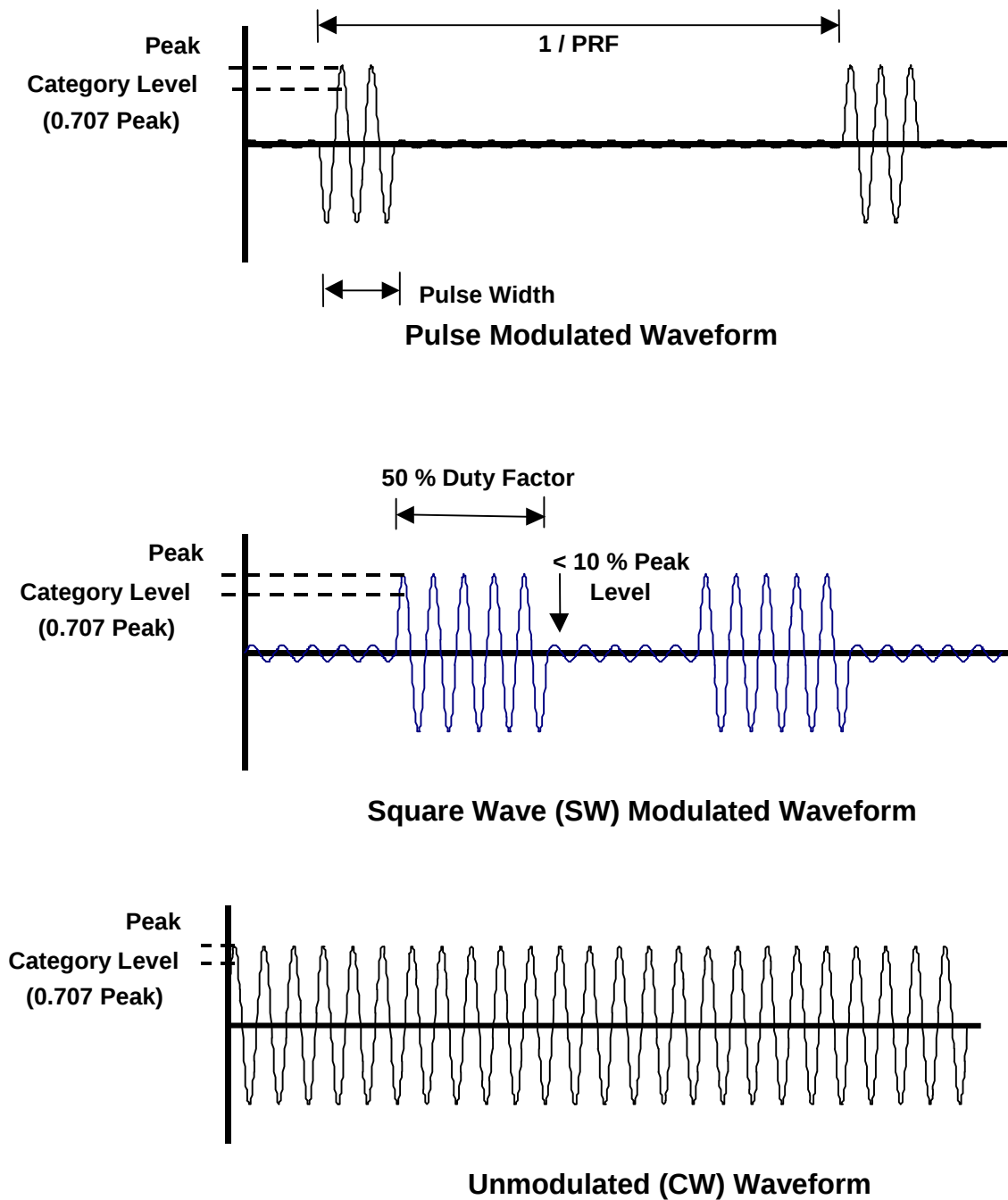


FIGURE 20-5 AMPLITUDE MEASUREMENT

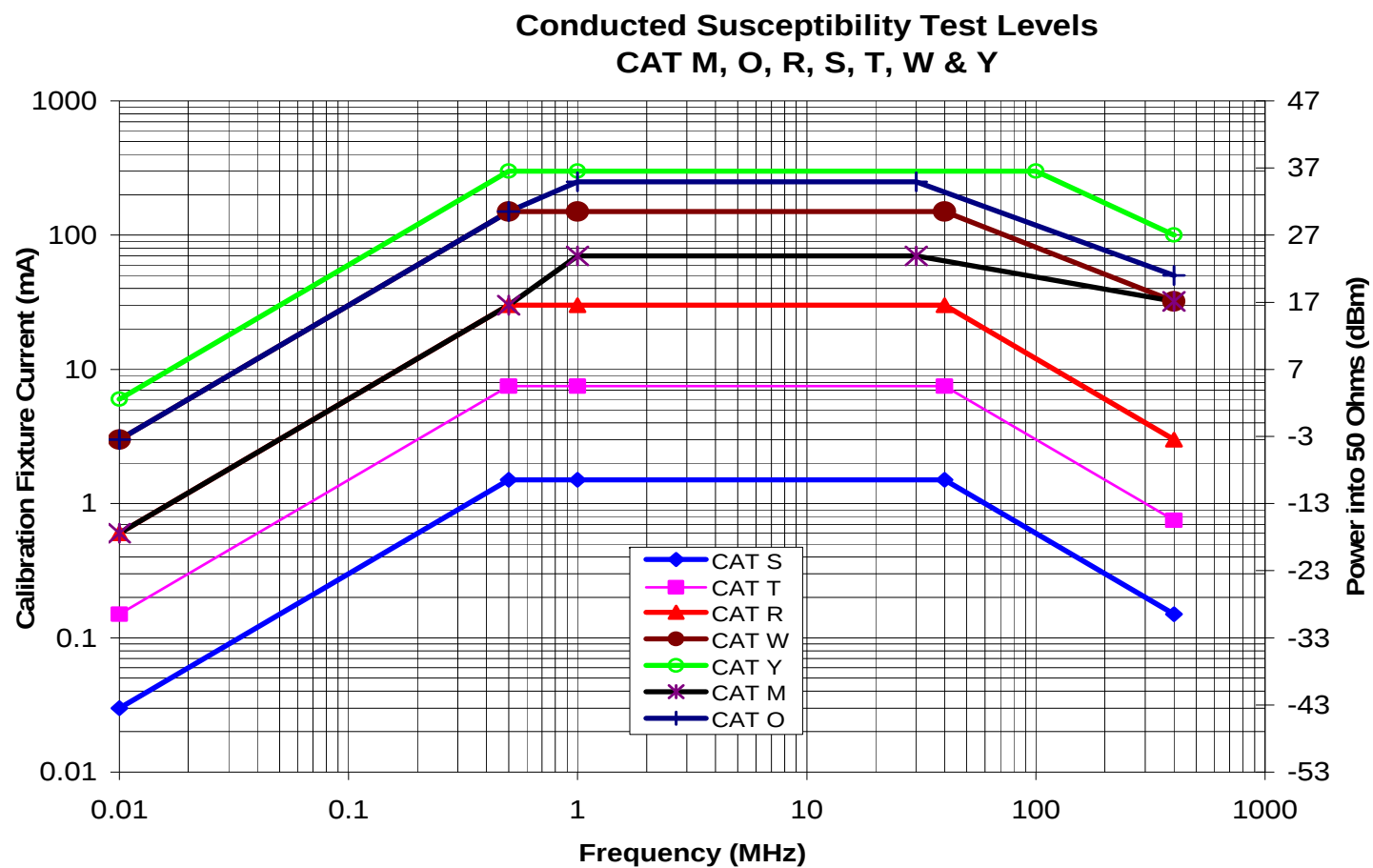


FIGURE 20-6 CONDUCTED SUSCEPTIBILITY TEST LEVELS

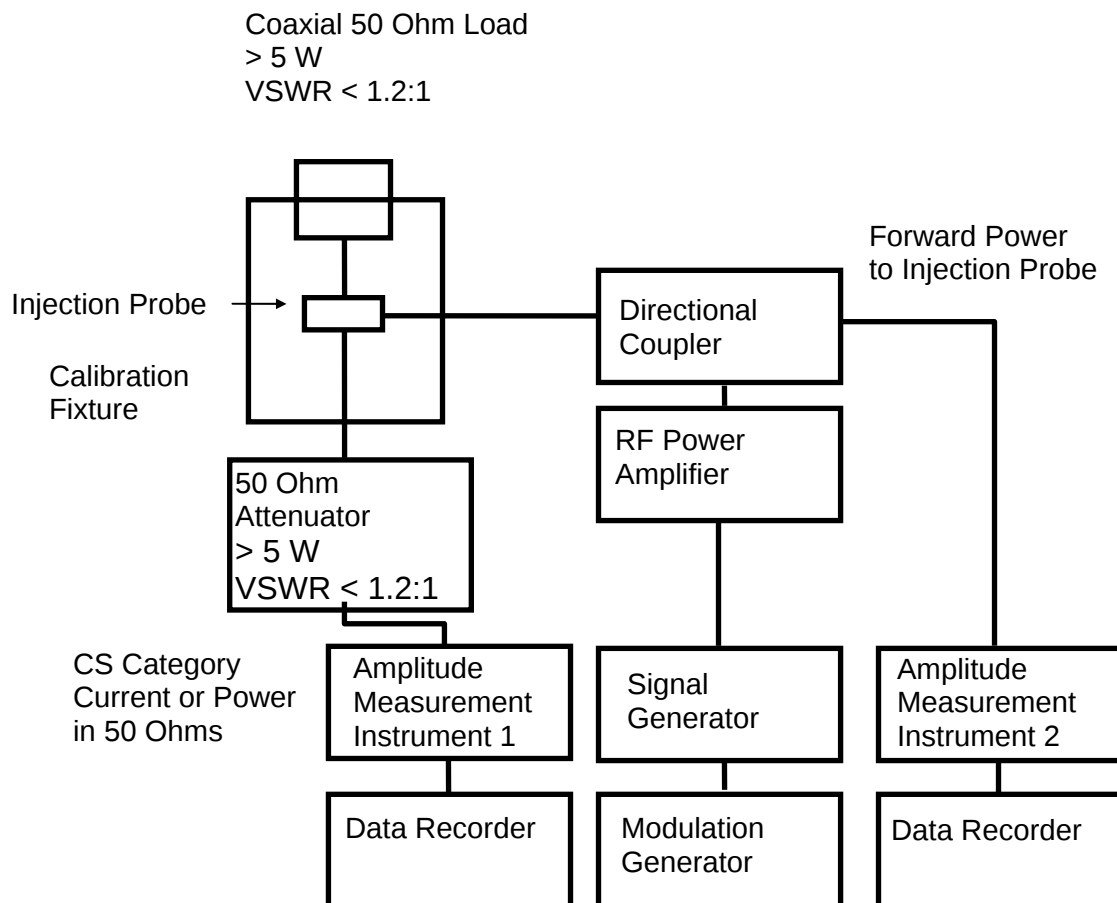
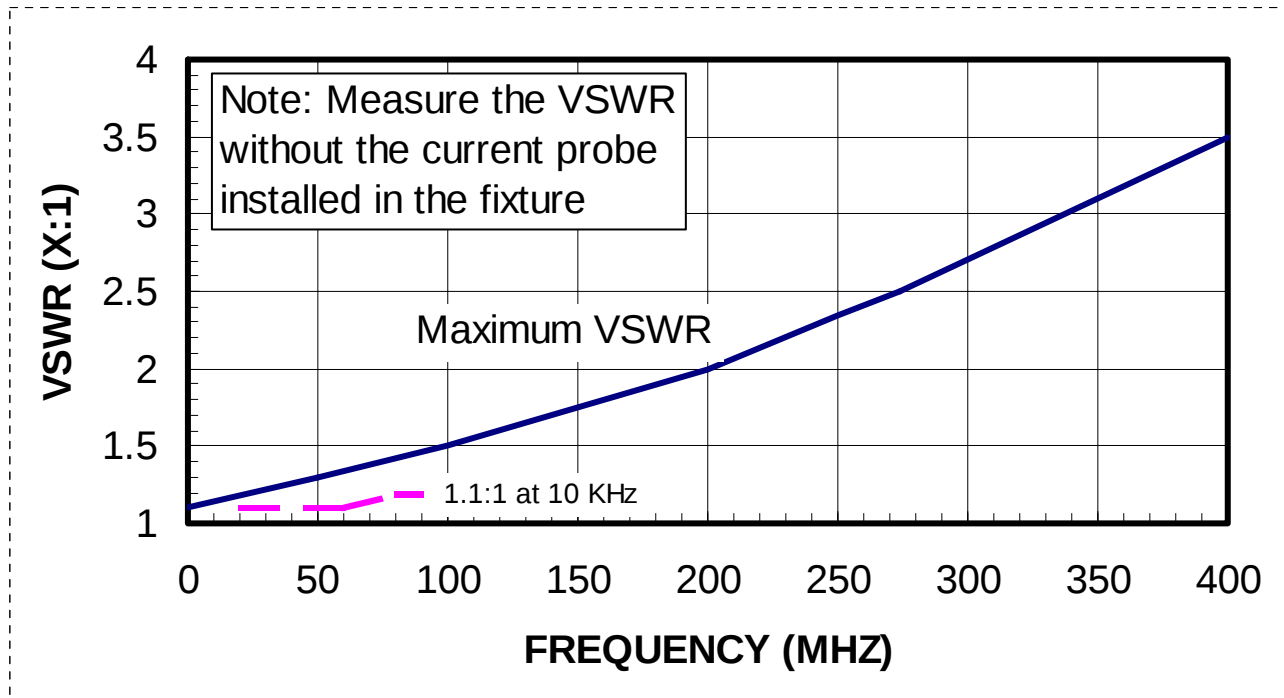
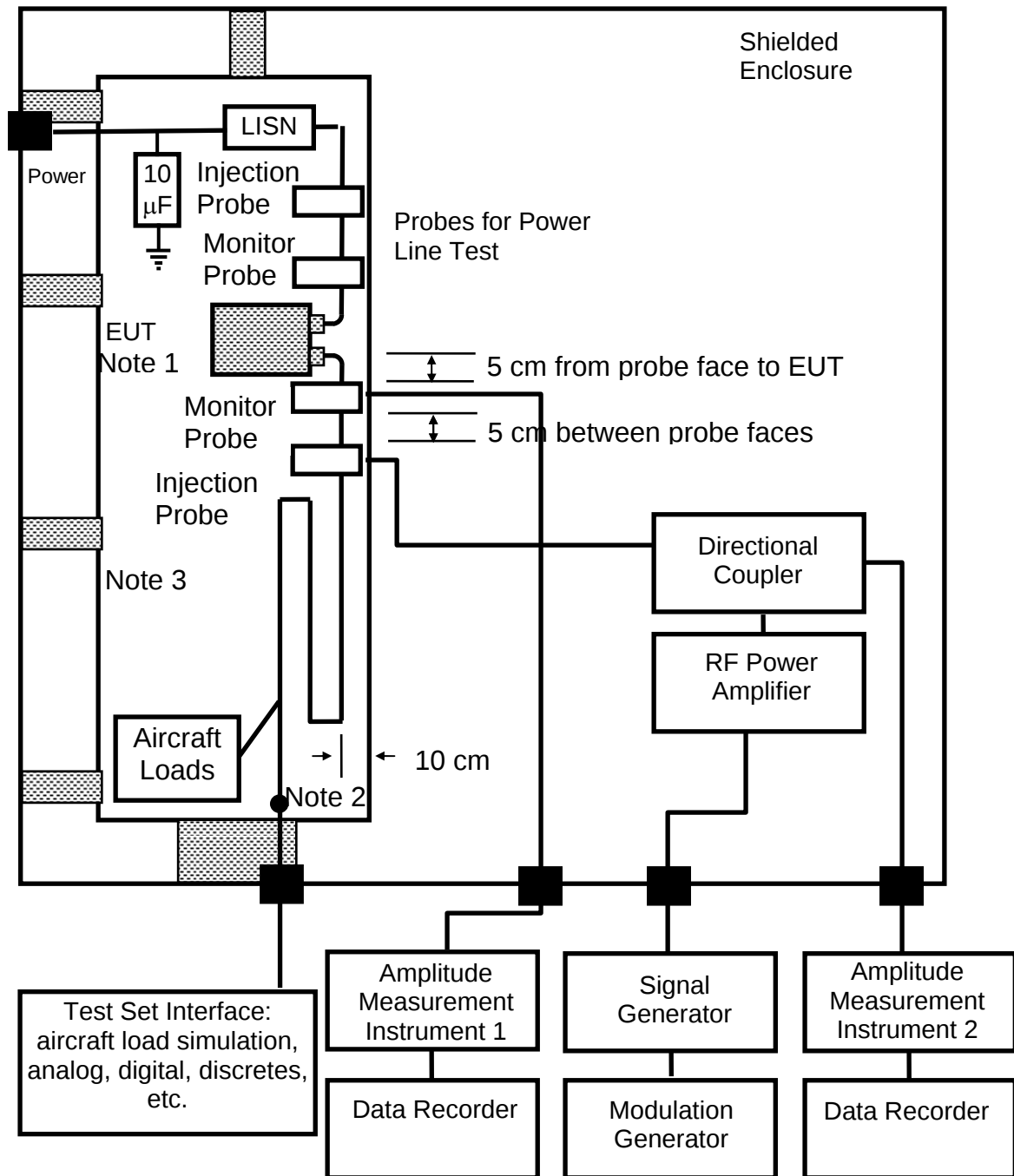


FIGURE 20-7 CONDUCTED SUSCEPTIBILITY CALIBRATION SETUP**FIGURE 20-8 CALIBRATION FIXTURE MAXIMUM VSWR LIMITS**



NOTE 1: See Section 20.3 for EUT general requirements.

NOTE 2: End of exposed cable. Unshielded cable may be shielded from here to the wall.

NOTE 3: Bonding strap.

FIGURE 20-9 CONDUCTED SUSCEPTIBILITY TEST SETUP

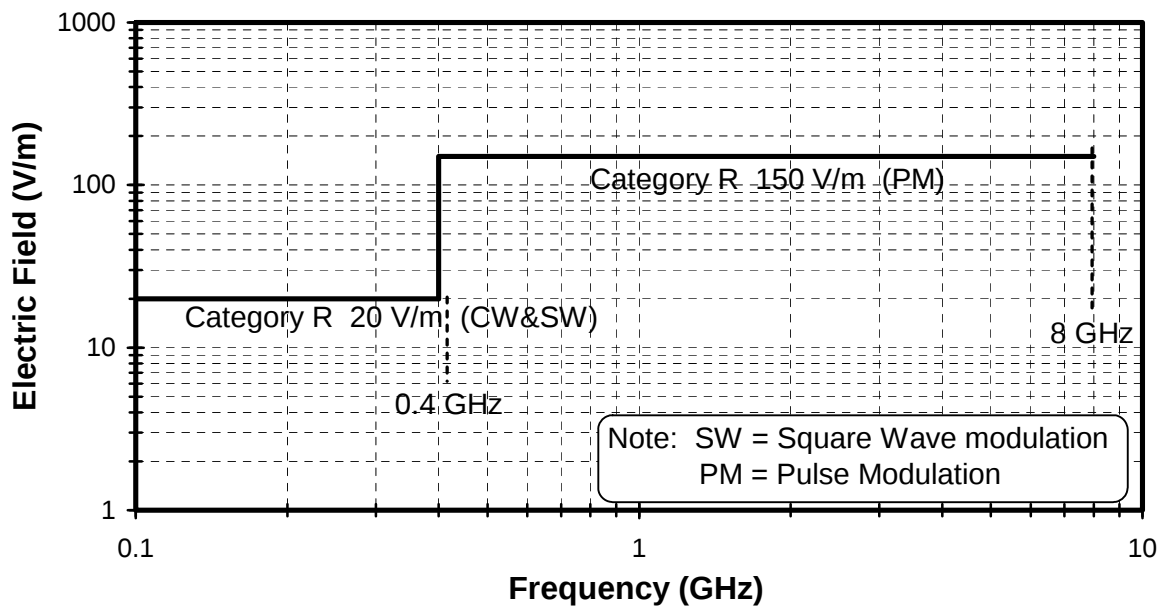
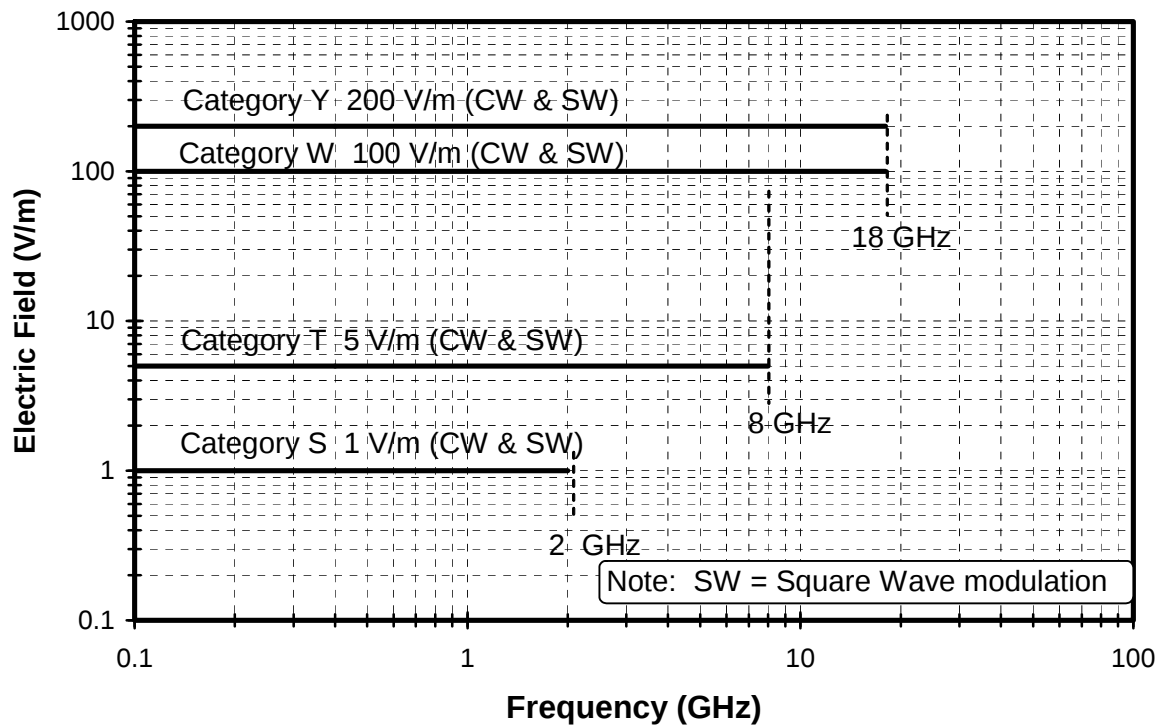


FIGURE 20-10(A &B) RADIATED SUSCEPTIBILITY TEST LEVELS

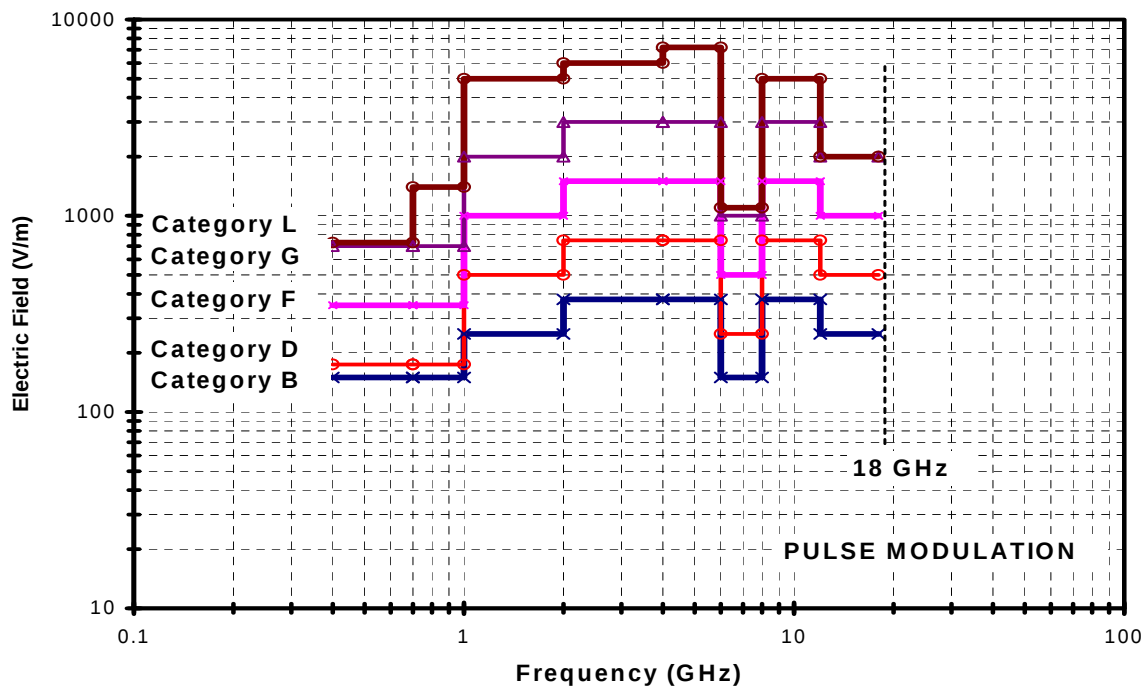
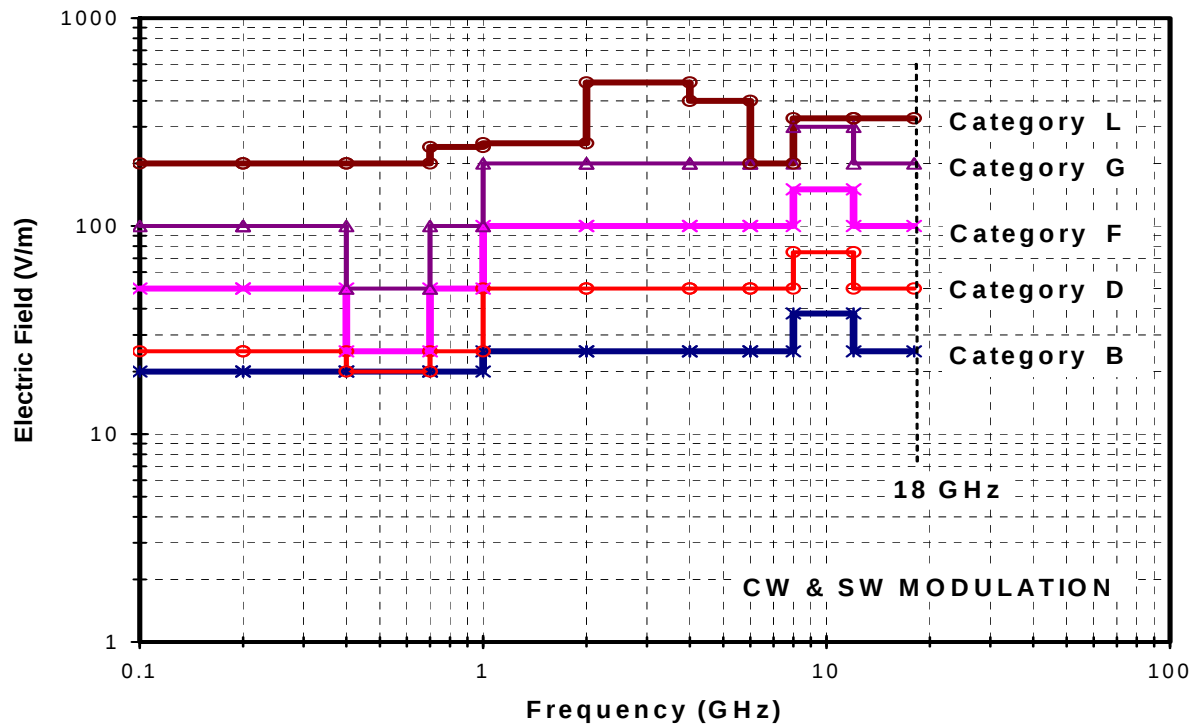


FIGURE 20-10 (C&D) RADIATED SUSCEPTIBILITY TEST LEVELS

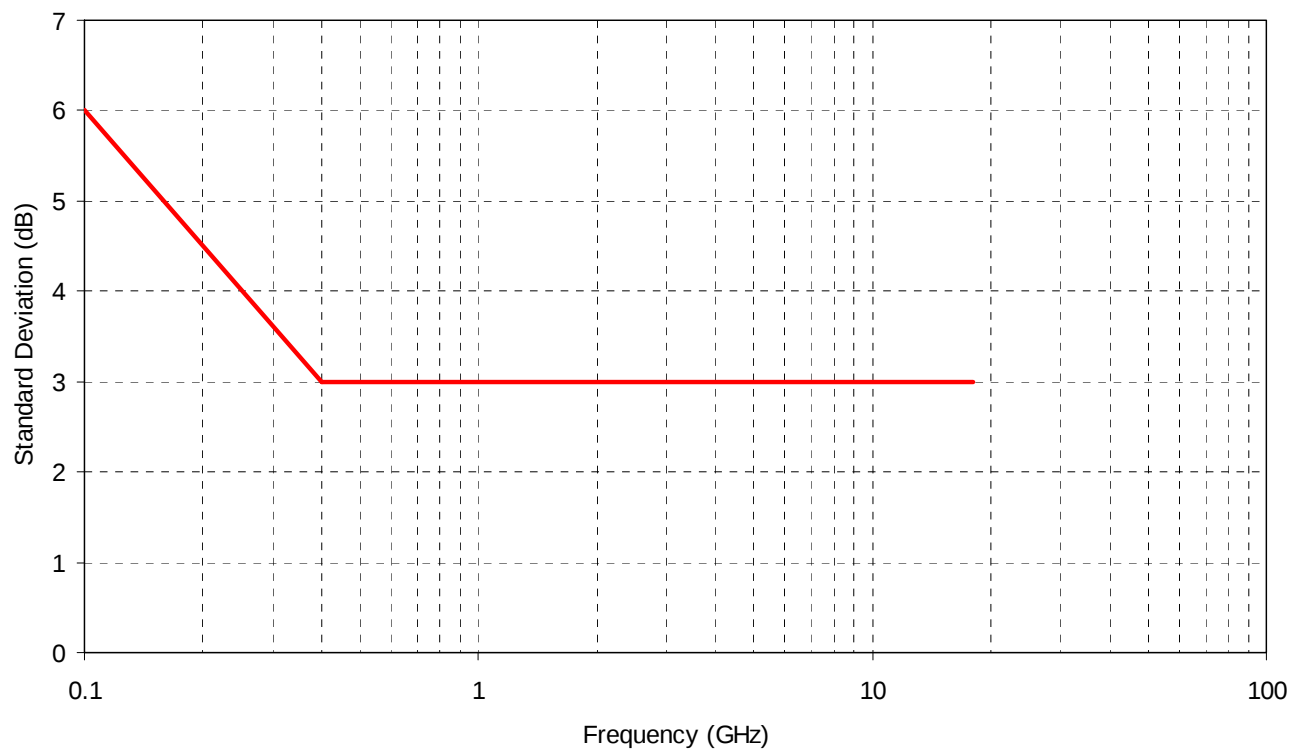
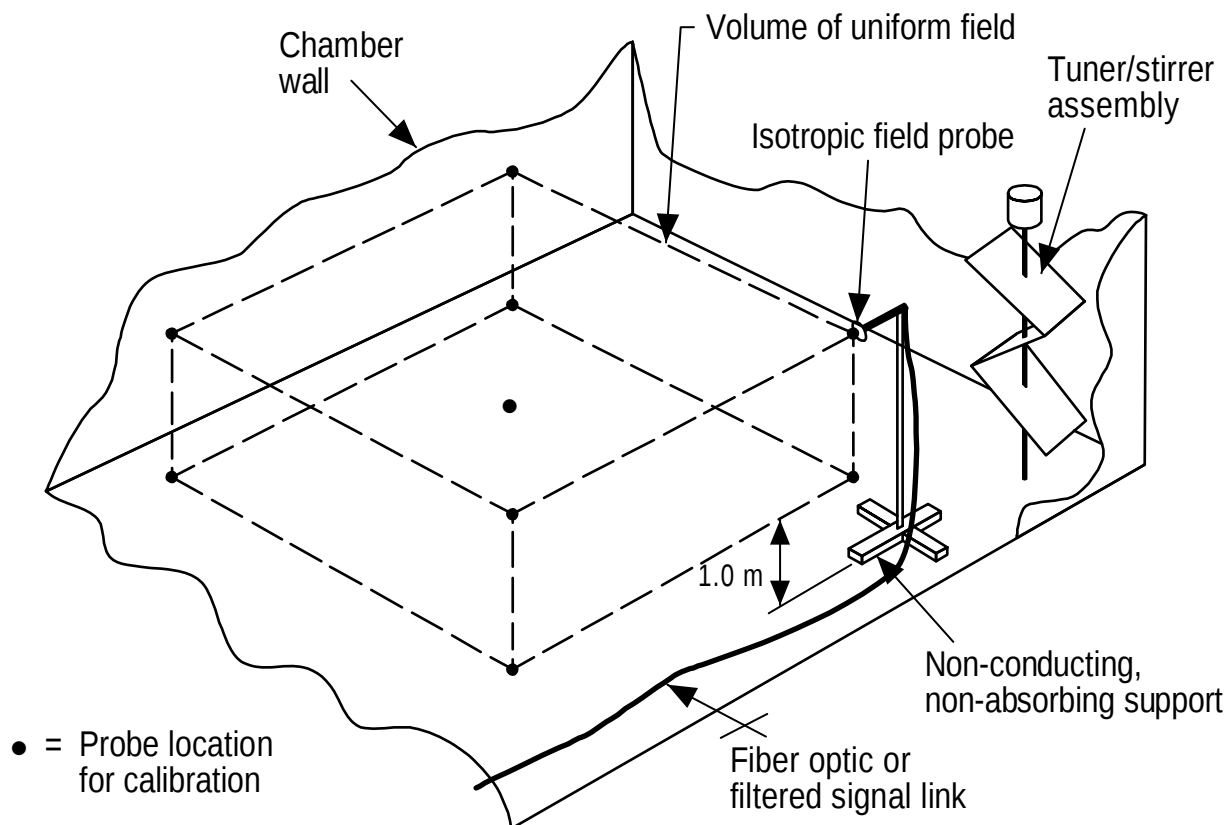


FIGURE 20-11 ALLOWABLE STANDARD DEVIATION FOR FIELD UNIFORMITY TEST



NOTE 1: Calibration of the fields inside the reverberation chamber shall consist of nine probe locations.

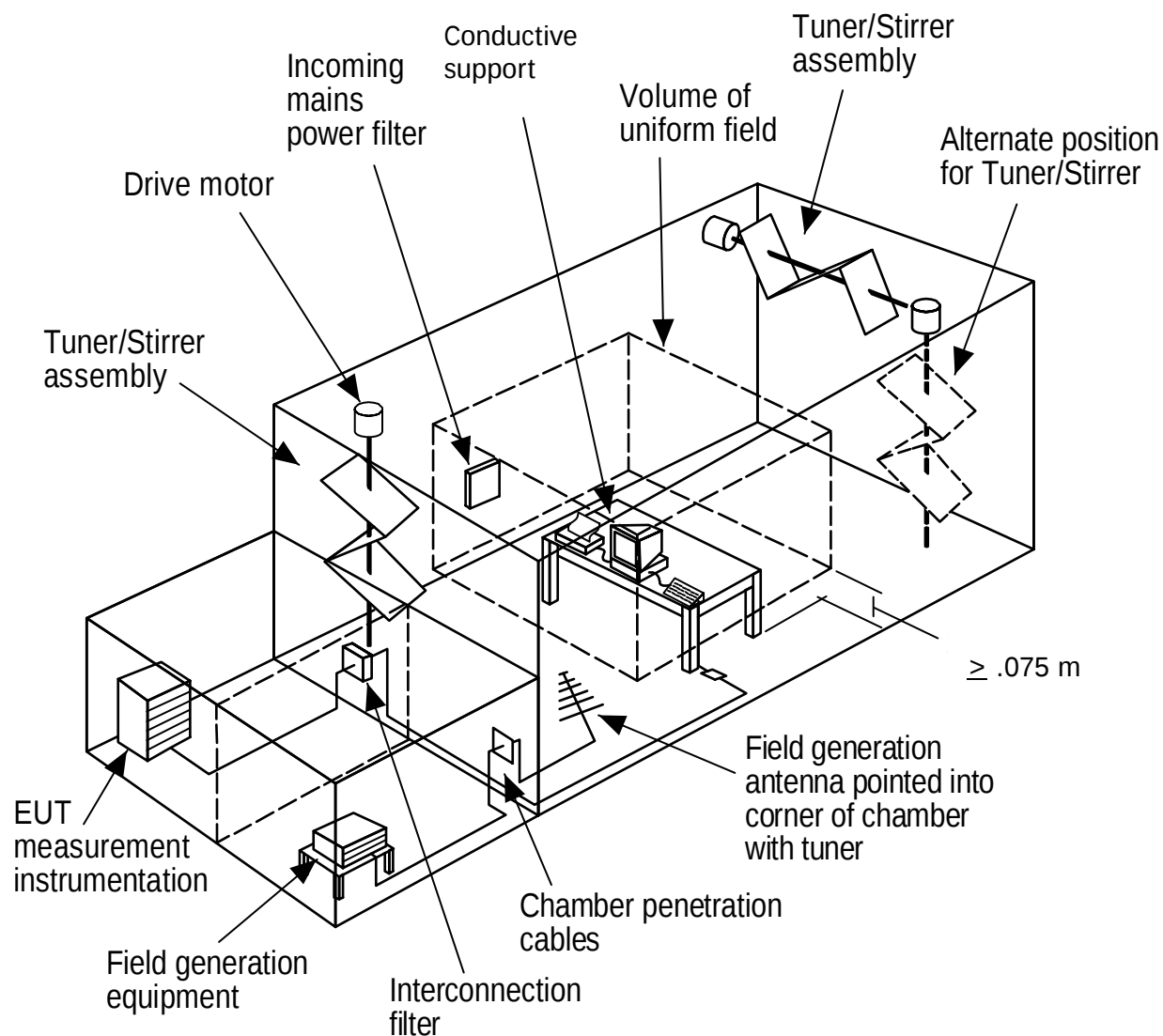
NOTE 2: The locations shall enclose a volume as shown above. This volume is the “working volume” of the chamber. The surfaces bounding the working volume should not be located closer than 0.75 meter (or $\lambda/4$ at the lowest test frequency) from any chamber surface, field generating antenna or tuner assembly. For calibration and monitoring purposes the receive antenna may be located at any location within the working volume. The transmit antenna should be directed into a corner of the chamber if possible. Directing the antenna into the tuner is also acceptable. The location of the transmit antenna shall remain fixed during calibration and testing. The location of the transmit antenna shall be the same for both calibration and testing.

NOTE 3: The working volume may be sized to suit the maximum working volume of the chamber or sized to suit the items to be tested. It is recommended that the working volume be sized to suit the maximum working volume since a second calibration will be required if larger items are to be tested.

NOTE 4: An isotropic probe which provides access to each of the three axes shall be used to conduct calibrations. A calibrated electrically short dipole antenna (i.e. less than 0.1 m) may be substituted provided that the dipole antenna is positioned at three mutually perpendicular orientations for each measurement location. Care should be taken to ensure that the dipole is not influenced by its connecting cable. An optically isolated measurement system (isotropic probe or dipole) is recommended.

NOTE 5: The minimum separation distance may be reduced to less than 0.75 meter provided that the separation is greater than $\lambda/4$ for the lowest test frequency. Separation distances of less than 1/4 meter are not recommended in any case.

FIGURE 20-12 PROBE LOCATIONS FOR REVERBERATION CHAMBER CALIBRATION



NOTES:

(1): Working volume must be at least .75 meter (or $\lambda/4$) from any chamber surface, field generating antenna or tuner assembly.

(2): The chamber should remain free of any unnecessary absorbing materials. Items such as wooden tables, carpeting, floor covering, wall covering or ceiling tiles should not be used. Exposed light fixtures are also a source of potential loading. For new chambers, it is recommended that an evaluation of the chamber be conducted prior to installation of any support equipment other than doors, vents and access panels.

FIGURE 20-13 EXAMPLE OF SUITABLE REVERBERATION CHAMBER TEST FACILITY

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RTCA/DO-160G

**Environmental Conditions and Test
Procedures for Airborne Equipment**

User Guide to Section 20

**Radio Frequency Susceptibility
(Radiated and Conducted)**

**Based on
DO-160G Section 20**

Date of Issue:
December 8, 2010

Prepared by: RTCA SC-135

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User's Guide, Appendix 20

Section 20 defines test levels, test procedures and requirements. In order to properly interpret the procedures and requirements outlined in Section 20, a User's Guide is provided as an Appendix to Section 20.

The User's Guide includes rationale, guidance and background information for the environment, test procedures and requirements, guidance in applying the requirements, and lessons learned from aircraft and laboratory experience. This information should help user's understand the intent behind the requirements, should aid in tailoring requirements as necessary for particular applications and should help user's develop detailed test procedures based on the general test procedures in Section 20.

The User's Guide follows a parallel format to the main body of Section 20 for easy cross reference. Paragraph numbers corresponding to each paragraph in Section 20 are included the User's Guide. Where there is no additional information provided in the User's Guide, the paragraph header is provided but the following paragraph is left blank.

20.0 Radio Frequency Susceptibility (Radiated and Conducted

20.1 Purpose of the Test

20.2 Equipment Categories

20.3 General Requirements

Pass/Fail Criteria

Note the pass/fail criteria for showing compliance of equipment to the T-PED RF environment may be different from that used for the HIRF RF environment. The T-PED RF environment can be considered “steady state” where as the HIRF RF environment is considered “momentary”.)

20.4 Conducted Susceptibility (CS) Test

Experience has identified problems due to limit overshoot when applying full forward power to cables at resonant frequencies. It may be recommend to starting the test at reduced power to limit risk of encountering these problems. One method to deal with this concern above 500Khz, when bundle may resonate, is to reduce the injected power by 12 dB at each frequency step in order to minimize the risk of problem due to limit overshoot.

20.5 Radiated Susceptibility (RS) Test

In term of radiating the EUT with conventional radiated method, two different manners have been used. First method is to sweep or step the frequency range while maintaining the power output to the antenna. The second method is to stop illumination before stepping and then increase the power at next frequency up to the required level. These two methods may produce different results. The second method may be useful in detecting window effects. Such window effect is directly accounted for when using the reverberation chamber test procedure.

20.6 Radiated Susceptibility (RS) Test; Alternate Procedure-Reverberation Chamber

20.6.1 Applicability / Intent

20.6.2 Procedure

Although dwell times are not applicable in this section, the EUT and test equipment response time should be considered to verify that the stirring speed insures that the field evolution is slow enough to detect susceptibilities. This verification should be documented as well in the test report.

20.6.2.a Test Procedure: Prior to start of the test

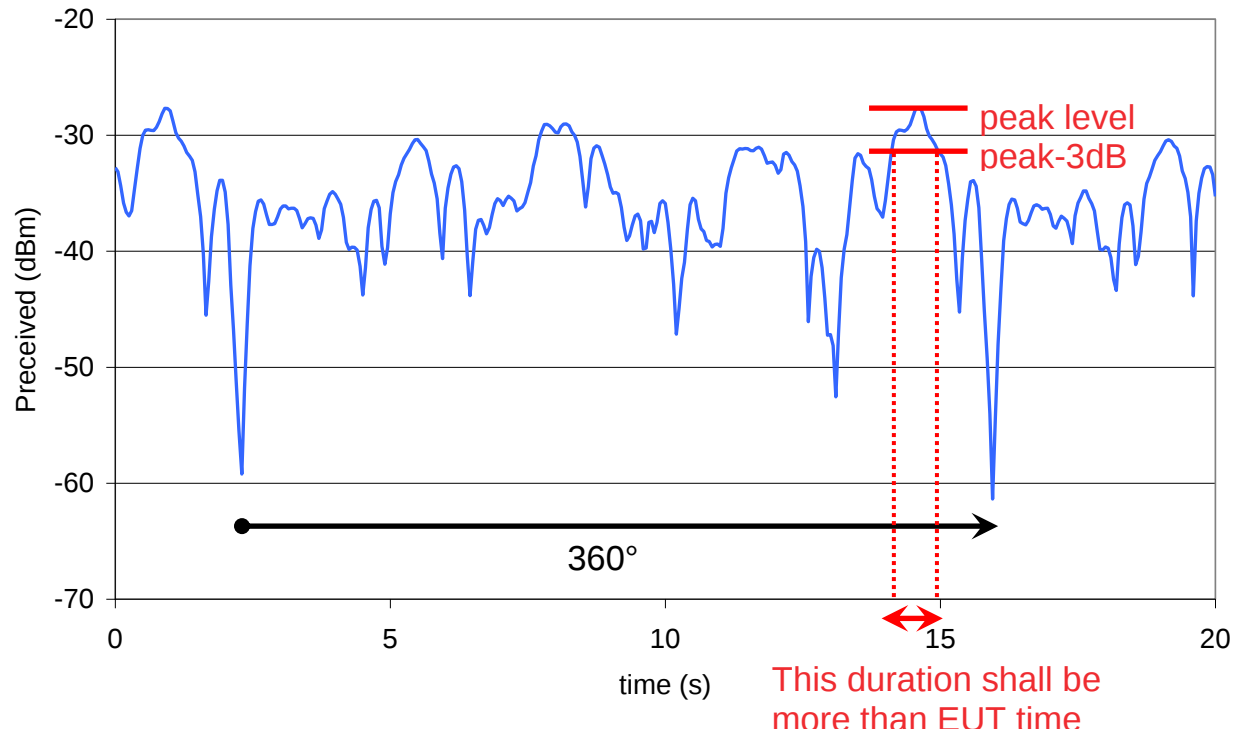
The accuracy of the equation in 20.6.2.b.iii describing the relation between the field strength within the chamber and the received power can be determined. The receive antenna as used in Section 20.6.3.1 should be placed in the test volume. Using the results of the received power on the antenna and the E field probes measurement performed in 20.6.3.1, the equation which provides the relation between the maximum field strength inside the chamber (V/m) and the maximum recorded power measured over one paddle rotation (W) used in 20.6.2.b.iii below can be validated.

20.6.2.c Test Procedure: EUT Test

Field stability may be a key issue for test homogeneity (as function of frequency), reliability (as function of EUT response time), repeatability (as function of Chamber and paddle wheel size). One proposal is provided below on how to define the lower frequency above which the standard procedure may be customized:

Rotate the tuner according to Section 20.6.2.c.ii. For a given test facility, the duration where the fields strength may remain above -3dB of the maximum value around the max field peak will be depending on the frequency. Slowing down tuner speed or stopping it at a number of positions may need to be required at higher frequencies when the instability of the field due to stirrer rotation may not give time for the EUT and/or associated monitoring equipment to react. Defining the frequency above which such improvement of the procedure needs to be considered will require definition of the EUT and/or monitoring equipment respond time and to correlate it with the histogram of the field in the room for a tuner rotation. An example of histogram and how to use it is provided in the figure below.

If stopping is chosen, then the number of position will be 12 as a minimum and may be increased to achieve higher level as described in 20.6.3.1.



Some thought has been given to defining a mode stirring procedure that would allow for multiple test frequencies within one tuner rotation at slower speed. Such a procedure would enable reasonable field stability without stopping the tuner rotation and without resulting in excessive test duration. The committee has not considered this procedure mature enough, in terms of supporting data, to be introduced in this issue of the document.

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 21

Emission of Radio Frequency Energy

Important Notice

Information contained in these sections is pertinent to all test procedures described in the other sections of this document. Further, Appendix A is applicable for identifying environmental tests performed.

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December 8, 2010

Supersedes: RTCA/DO-160F
Prepared by: SC-135

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21.0 Emission of Radio Frequency Energy

21.1 Purpose of the Test

These tests determine that the equipment does not emit undesired RF noise in excess of the levels specified below. The notches specified in the radiated emissions limits are included to protect aircraft RF sensors operating frequencies.

21.2 Equipment Categories

Categories are defined in terms of location and separation between the equipment and aircraft radio antennas. As these parameters are widely linked to aircraft type and size, some examples are given with each category definition.

Category B

This category is intended primarily for equipment where interference should be controlled to tolerable levels.

Category L

This category is defined for equipment and interconnected wiring located in areas far from apertures of the aircraft (such as windows) and far from radio receiver's antenna. This category may be suitable for equipment and associated interconnecting wiring located in the electronic bay of an aircraft.

Category M

This category is defined for equipment and interconnected wiring located in areas where apertures are electro-magnetically significant and not directly in view of radio receiver's antenna. This category may be suitable for equipment and associated interconnecting wiring located in the passenger cabin or in the cockpit of a transport aircraft.

Category H

This category is defined for equipment located in areas which are in direct view of a radio receiver's antenna. This category is typically applicable for equipment located outside of the aircraft.

Category P

This category is defined for equipment and associated wiring located in areas close to HF, VHF, or Global Positioning System (GPS) radio receiver antennas, or where the aircraft structure provides little shielding.

Category Q

This category is defined for equipment and associated wiring located in areas close to VHF, or GPS radio receiver antennas, or where the aircraft structure provides little shielding.

21.3 General Requirements

This section does not measure or control spurious signals conducted out of the antenna terminals of receivers or transmitters. That control should be specified in the equipment performance standard for that receiver or transmitter. Radio transmitters or receiver/transmitters must meet specified emissions requirements (including the selected frequency $\pm 50\%$ of the band of frequencies between adjacent channels) while in a non-transmitting or receive mode.

Note: Do not measure radiation emanating from antennas or, in the case of transmitters, any radiation on the selected frequency $\pm 50\%$ of the band of frequencies between adjacent channels while the transmitter is keyed and supplying RF to the load.

The equipment under test shall be set up on a ground plane and operated in accordance with the criteria in Subsection **20.3** subparagraph **a** and subparagraph **b**, parts **1**, **2** and **5** with the following limitations and additions:

- a. For radiated emission measurements as in Subsection 21.5, antenna spacing to the ground plane edge and the EUT spacing from the ground plane edge shall be maintained as shown in Figure 21-11.
- b. Interference shall be measured using the peak detector function of the interference measuring equipment. Interference measuring instruments with selectable IF bandwidths (BW) may be used, and the selected BW must be the values given in Table 1.
- c. Line Impedance Stabilization Networks (LISNs) shall be used as shown in Figure 21-6. Figure 20-1 provides technical data for a LISN.
- d. Power return wires tied locally to the ground plane as noted in Section 20.3.a (6) are not tested.
- e. The time constant of the peak detector must be lower or equal to $1/BW$. Where applicable, video bandwidths shall be selected to be greater than or equal to the resolution bandwidth.
- f. Longer dwell, sweep and measurement times than those shown in Table 1 may be necessary to detect time-varying emissions. Dwell times in Table 1 are associated with a potential rate of variation of approximately 60 Hz.
- g. For emission measurements, the entire frequency range for each applicable test shall be scanned. Minimum measurement time for analog measurement receivers during emission testing shall be as specified in Table 1. Synthesized measurement receivers shall step in one-half bandwidth increments or less, and the measurement dwell time shall be as specified in Table 1. Larger receiver bandwidths may be used; however, they may result in higher measured emission levels.

NO BANDWIDTH CORRECTION FACTORS SHALL BE APPLIED TO TEST DATA DUE TO THE USE OF LARGER BANDWIDTHS.

- h. Recorded data shall provide a minimum frequency resolution of 1% or twice the measurement receiver bandwidth, whichever is less stringent, and minimum amplitude resolution of 1 dB.
- i. Amplitude versus frequency profiles of emission data shall be automatically generated and shall be continuous.
- j. Data Required In Test Report - The test report shall include the following test setup and data items.
 1. Cable Configuration(s) - The length of each cable bundle, types of wiring, shielding and shield terminations (including individual as well as overall shields), and the wiring diagram of the test harness.
 2. Test Setups - Schematic or block diagrams or photographs of each test setup including layout of cable bundles, placement of transient injection and measurement probes and EUT bonding methods.
 3. EUT Operating Mode(s) - The mode(s) of operation used during emissions tests.
 4. Load(s) - A description of all loads, either actual or simulated. Simulated loads shall identify the extent of impedance simulation both line-to-line and line-to-case (ground).

Table 1 Bandwidth and Measurement Times

Frequency Band	6dB Bandwidth (BW)	Minimum Dwell Time (seconds) for Sections 21.4 and 21.5	Minimum Sweep Time for Frequency Band (seconds) for Section 21.6	Minimum Measurement Time for Analog Measurement Receivers
.150 to 30 MHz	1 KHz	0.015	N/A	0.015 sec/KHz
30 to 100 MHz	10 KHz	0.015	N/A	1.5 sec/MHz
100 to 400 MHz	10 KHz	0.015	9	1.5 sec/MHz
.400 to .96 GHz	100 KHz	0.015	1	0.15 sec/MHz
.96 GHz to 6 GHz	1 MHz	0.015	1	15 sec/GHz

Note 1: It may be necessary to use an in-line low noise preamplifier at the sense antenna output in cascade with the measurement receiver to lower the measurement noise floor for proper measurements in the notches above 960 MHz defined for categories M, H, & P and Q.

Note 2: For measurement receivers or spectrum analyzers with a “maximum hold” feature that retain maximum detected levels after multiple scans over a given frequency range, multiple faster sweeps that produce the same minimum test times as shown in Table 1 are acceptable.

21.4 Conducted RF Emissions

Measure conducted emissions from 150 KHz to 152 MHz. Interference currents generated by the equipment shall be measured by using a clamp-on interference measuring device.

- a. EUT emissions within the frequency ranges and in excess of the values given in Figure 21-1, Figure 21-3 or Figure 21-4 shall not appear on any power line normally connected to an aircraft bus.
- b. EUT emissions within the frequency ranges and in excess of the values given in Figure 21-2, Figure 21-3 or Figure 21-5 shall not appear on any interconnecting cable bundles. Primary power lines are not considered to be interconnecting cable bundles. *Antenna feed cables are considered to be interconnecting cables while in a non-transmitting or receive mode.*
- c. Figure 21-6 shows a simplified test arrangement for the use of the current probe.
- d. Install the current probe five centimeters from the EUT. If the EUT connector plus back shell length exceeds five centimeters the probe shall be placed as close to the connector back shell as possible and the position noted.
- e. Measure and record the EUT emissions and apply the appropriate limit from Figures 21-1, 21-2, 21-3, 21-4, or 21-5 for the selected category.

21.5 Radiated RF Emission

Measure radiated emissions from 100 MHz to 6000 MHz.

- a. Radiated interference fields generated by the equipment within the frequency ranges, and in excess of the values shown in Figures 21-7, 21-8, 21-9 and 21-10 for the appropriate categories, shall not be radiated from any unit, cable or interconnecting wiring.
- b. A typical arrangement of equipment for conducting the radiated RF emission test is shown in Figure 21-11.
- c. Field strength units are obtained by using any appropriate antenna and adding the appropriate antenna factor to the measured voltage in dB microvolts. Appropriate correction factor for cable losses and matching networks must also be applied.
- d. Linearly polarized antennas are required for radiated tests. Measure radiated emissions using both vertically and horizontally polarized orientations.
- e. Directly expose apertures in the EUT (e.g., displays, CRTs, connectors) to the receiving antenna, which may require additional EUT orientations or receive antenna positions. If all EUT apertures are not exposed to the receive antenna, justification must be documented in the test report.

- f. Consider EUT realistic operating modes which produce maximum emission.
- g. Radiated ambient data (EUT “off” and test support equipment “on”) is required only if EUT emissions are greater than 3 dB below the selected category limit.
- h. It is good engineering practice to check ambient radiated emissions prior to a radiated emissions test, and it is desirable that the ambient emissions be at least 6 dB below the selected limit line.
- i. Measure and record the EUT emissions conditions and apply the appropriate limit from Figures 21-7, 21-8, 21-9 or 21-10 for the selected category.

21.6 Radiated RF Emissions; Reverberation Chamber Procedure

Reverberation chamber radiated RF emissions measurements defined in this section may be used in place of the radiated RF emissions measurements in section 21.5.

21.6.1 Reverberation Chamber Requirements

The reverberation chamber must use continuous rotation of the chamber tuner (mode stirring). The reverberation chamber must meet the field uniformity requirements of Section 20.6.3 at or above 100 MHz.

21.6.2 Reverberation Chamber Insertion Loss

- a. Install the test bench(s), EUT, and wiring in the reverb chamber. The EUT should be unpowered. Any support equipment should be unpowered. The equipment and wiring arrangement shall meet the requirements specified in Section 20.3.a. (5). The EUT and associated wiring shall be within the working volume as defined in Figure 20-13. A simplified diagram is shown in Figure 21-12.
- b. The receive antenna shall be in band for the EUT test frequencies. The receive antenna location must meet the uniformity requirements of 20.6.3. If the receive antenna is mounted in a fixed position during routine testing, it is required that one of the locations used during uniformity verification must be at the intended permanent location of the receive antenna.

Note: It is critical to minimize direct coupling effects between the receive antenna and EUT.

- c. Select the spectrum analyzer or EMI receiver peak detector mode and set the display for peak hold.
- d. Set the signal generator to sweep a range of frequencies as given in Table 1. Divide the sweep time of the signal generator by 100 and set the spectrum analyzer sweep time to that value with a 1 MHz IF BW. Multiply the signal generator sweep speed by 100 to obtain the minimum time for one tuner rotation.
- e. With the RF signal generator sweeping the range of frequencies chosen in 21.6.2(d.), adjust the RF source to inject a known input power, P_{input} , into the transmit antenna. The transmit antenna shall not directly illuminate the working volume or the receive antenna. The range of frequencies scanned shall be in band for the linearly polarized transmit antenna. **Care should be taken to ensure the measurements are above the noise floor of the measuring device.**
- f. Record the RF signal generator output power in dBm (P_{input}).

- g. Rotate the tuner through one full rotation so that the spectrum analyzer or EMI receiver captures the peak power from the receive antenna across the selected frequency range. Perform the required spectrum analyzer sweeps specified in 21.6.3(e.).
- h. Calculate the insertion loss of the reverb chamber by using the following formula:

$$IL = (P_{input} - L_{loss}) + (10 \log(\eta)) - P_{rec}$$

Where:

IL = loaded insertion loss in dB at a given frequency

P_{input} = RF signal generator output power in dBm

L_{loss} = transmit antenna line loss in dB

η = transmit antenna efficiency. The antenna efficiency can be assumed to be .75 for a log periodic antenna and .9 for a horn antenna,

P_{rec} = received power in dBm

Note: The same receive antenna and receive antenna transmission line must be used for the insertion loss measurement and the radiated RF emissions measurement.

21.6.3 Radiated RF Emissions Test

The reverberation chamber RF emissions test measures the power emitted by the EUT. The total EUT RF emissions power is calculated by adding the insertion loss of the chamber (in dB) to the measured EUT RF emissions power (in dBm) at each measurement frequency.

Apply power to the EUT and verify proper operation. Any necessary support equipment should be powered and allowed to stabilize. The equipment and wiring arrangement shall meet the requirements specified in Section 20.3.a. (5). The EUT and associated wiring shall be within the working volume as defined in Figure 20-13.

- a. Select EUT operating modes which produce maximum emission.
- b. Disconnect the transmit antenna transmission line from the signal generator outside the shield room and terminate this transmission line to the antenna with a 50 ohm load as shown in Figure 21-13.
- c. The receive antenna must meet the requirements in **21.6.2. (b)**.
- d. Set the spectrum analyzer or EMI receiver to monitor the receive antenna at the bandwidth specified in paragraph **21.3 Table 1**.
- e. Select the spectrum analyzer or EMI receiver peak detector mode and set the display for peak hold.

- f. Select the sweep time of the spectrum analyzer or EMI receiver as specified in **21.3 Table 1**. Multiply the sweep time of the analyzer or EMI receiver by 200 to obtain the time for one rotation of the tuner.
- g. Rotate the tuner through one full rotation so that the spectrum analyzer or EMI receiver captures the peak power from the receive antenna across the chosen range of frequencies. A minimum of 200 sweeps is required for one tuner rotation.
- h. Calculate the EUT RF emissions power using the following formula:

$$P_t = \frac{10^{(P_{rec} + IL)/10}}{1000}$$

Where:

P_t = total power in watts emitted by the EUT at a given frequency

P_{rec} = max power in dBm from the receive antenna

IL = insertion loss in dB calculated in **21.6.2(h)**

- i. Calculate the electric field strength E .

$$E = \sqrt{\frac{D * P_t * 377}{4 * \pi}}$$

Where:

E = field strength in volts per meter

P_t = max power in watts from **21.6.3 (h)**

$D = 1.64$, the equivalent directivity of the EUT.

Note: The directivity of the EUT is assumed to be equivalent to a half-wave dipole antenna.

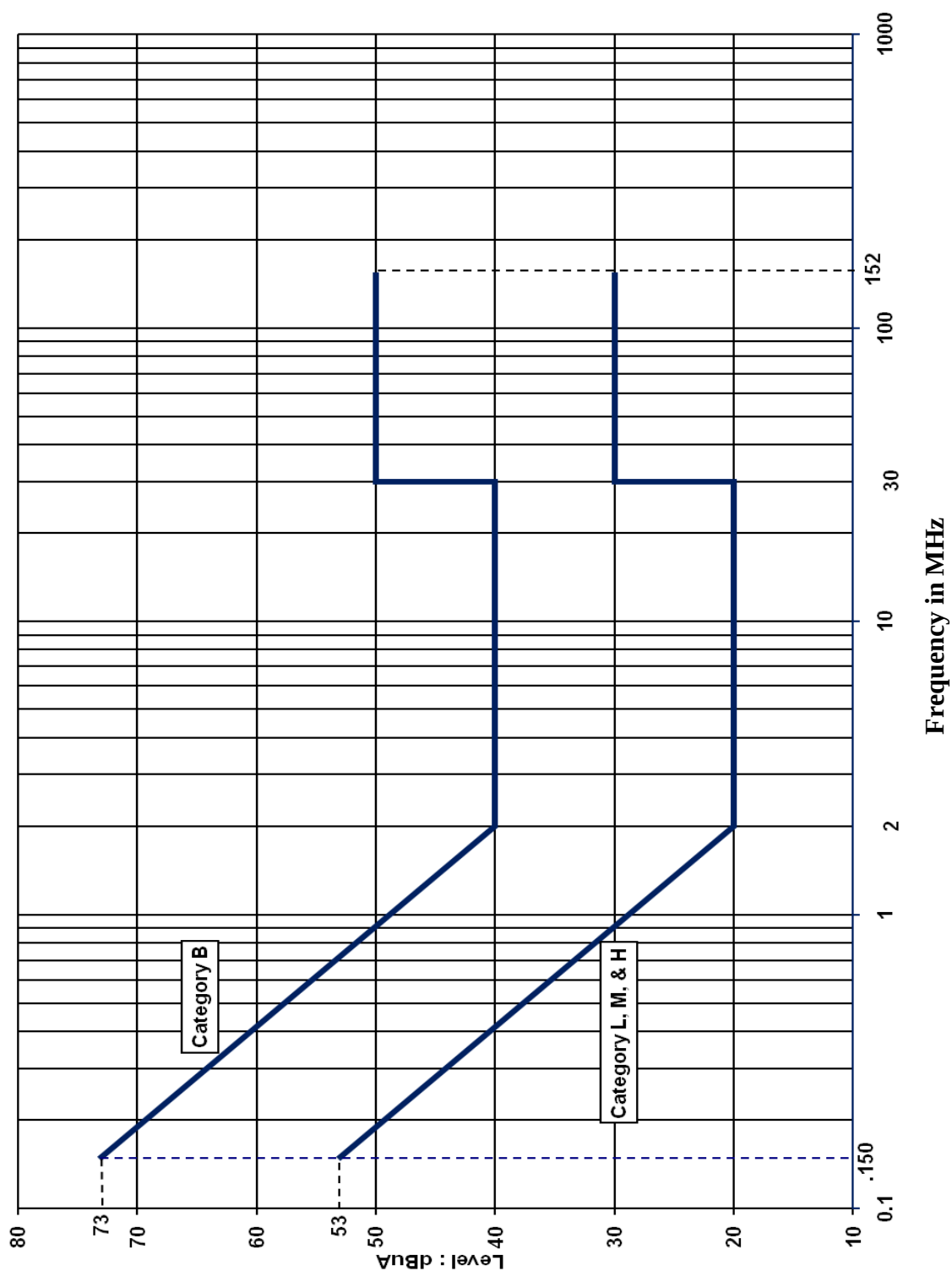
- j. Calculate the electric field emissions (dBuV/m).

$$dBuV / m = (20 \log(E)) + 120$$

Where:

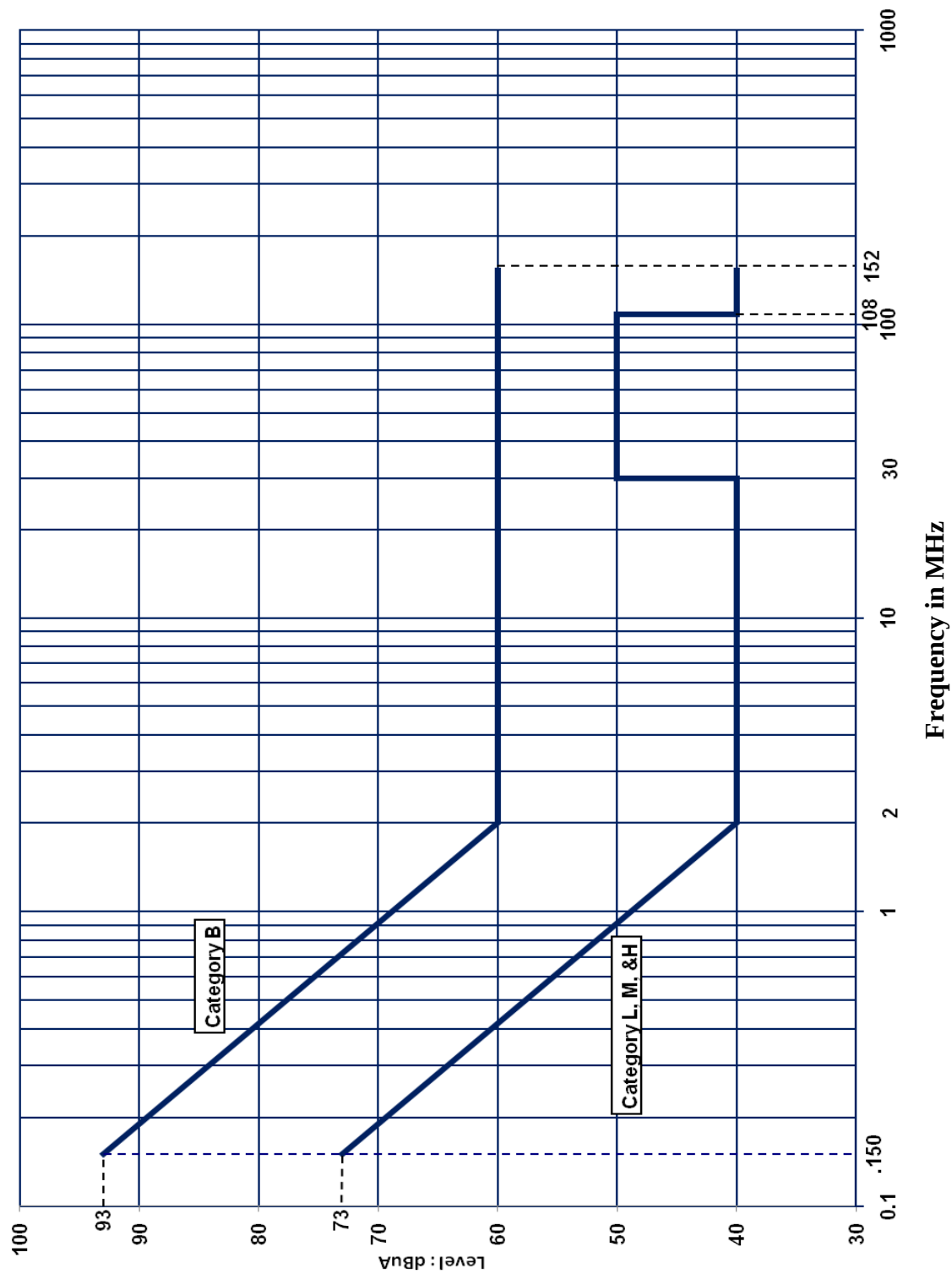
E = field strength in volts per meter from **21.6.3 (i)**

- k. Record the EUT electric field emissions and apply the appropriate limit from Figures 21-7, 21-8, 21-9 or 21-10 for the selected category.
- l. Measure the ambient radiated RF (EUT “off” and test support equipment “on”) if EUT emissions are higher than the selected category limit minus 3 dB. It is good engineering practice to check ambient radiated emissions prior to a radiated emissions test, and it is desirable that the ambient emissions be at least 6 dB below the selected category limit.



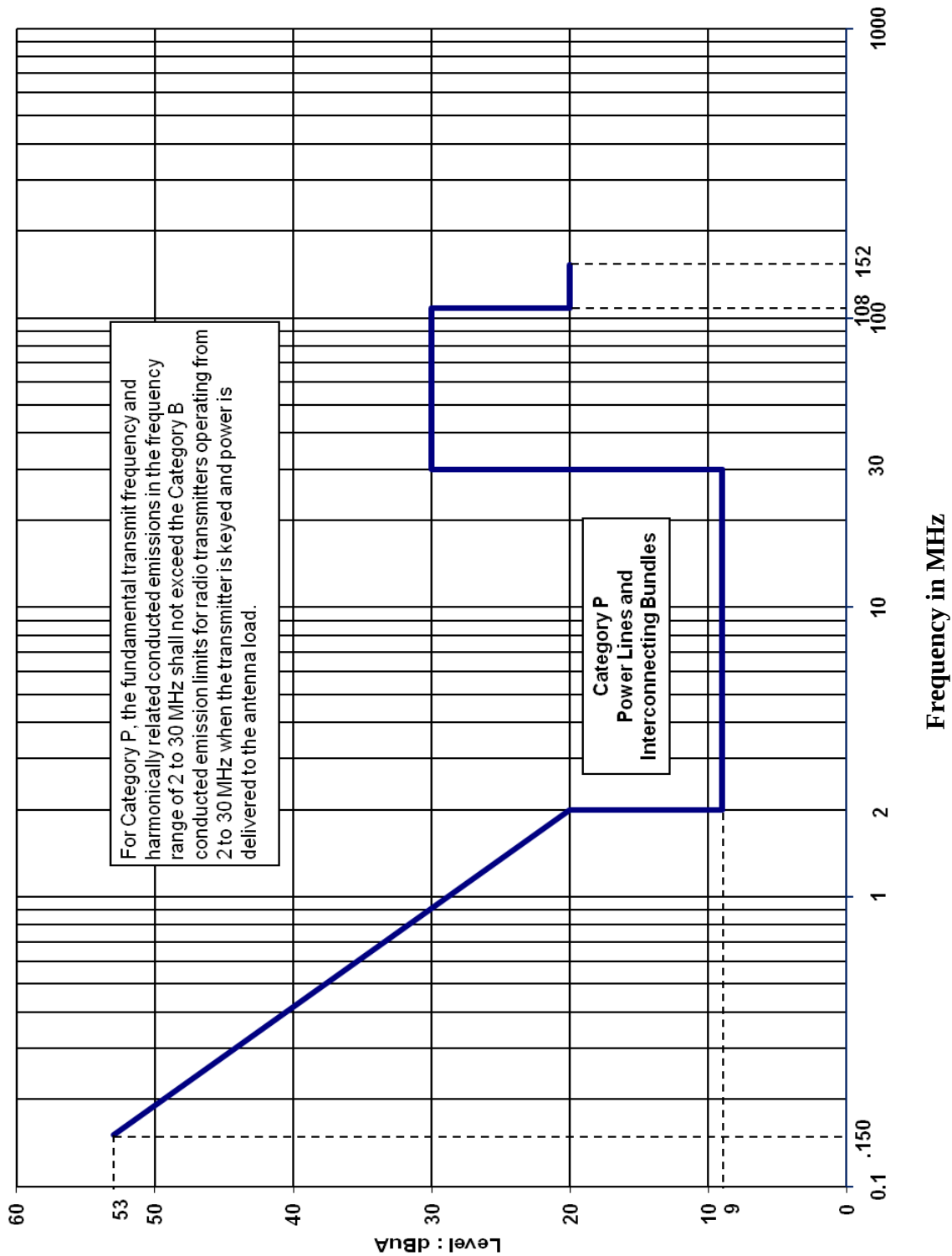
Curve definition : Limit Level = slope * log(freq in MHz) + intercept
 Category B: F<2 MHz slope = -29.335, intercept = 48.83
 Category L,M,&H: F<2 MHz slope = -29.335, intercept = 28.83

Figure 21-1 : Maximum Level of Conducted RF Interference – Power Lines



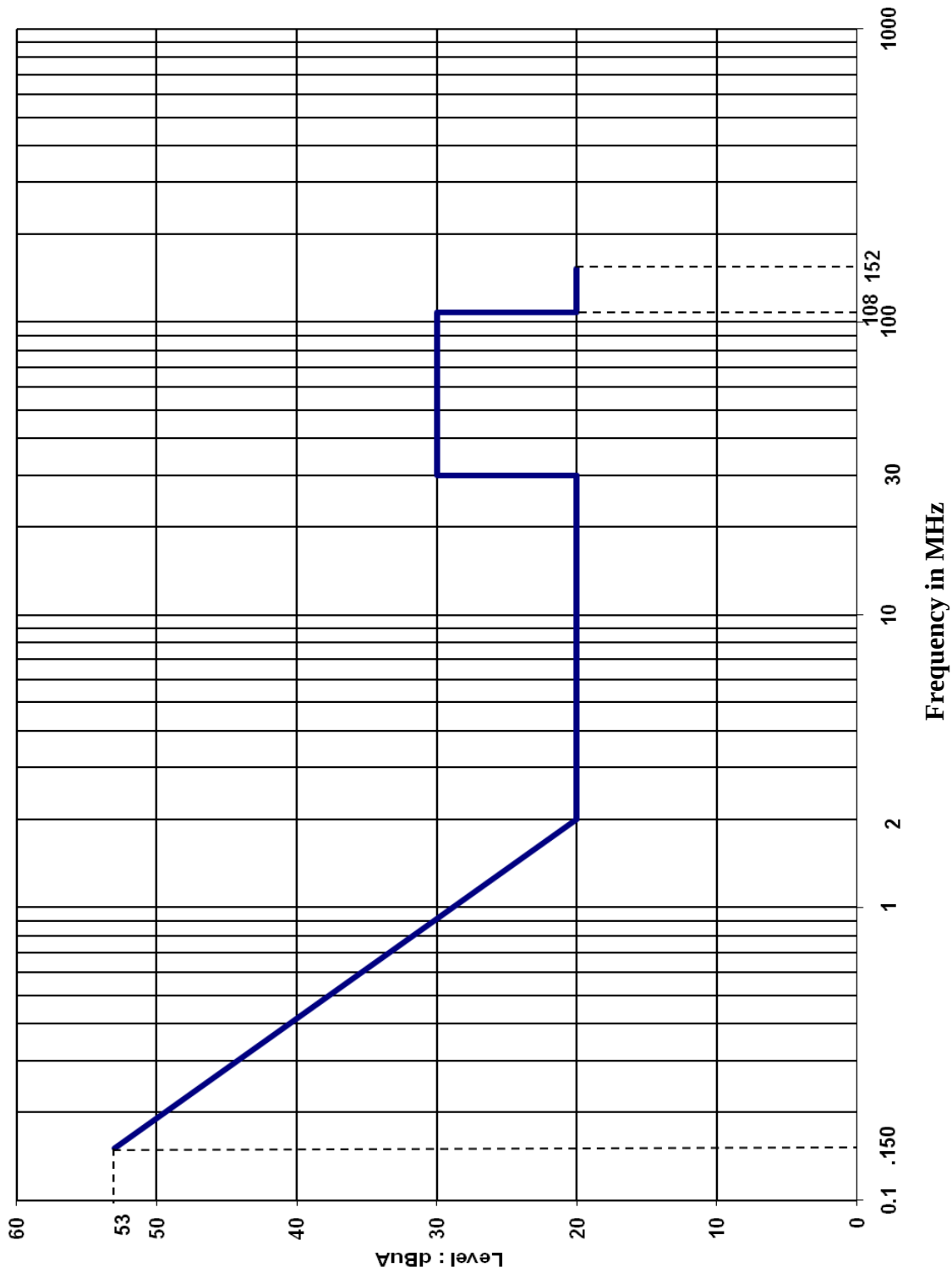
Curve definition : Limit Level = slope * log(freq in MHz) + intercept
 Category B: F<2 MHz slope = -29.335, intercept = 68.83
 Category L, M & H: F<2 MHz slope = -29.335, intercept = 48.83

Figure 21-2 : Maximum Level of Conducted RF Interference – Interconnecting Bundles



Curve definition : Limit Level = slope * log(freq in MHz) + intercept
 Category P: F < 2 MHz slope = -29.335, intercept = 48.83

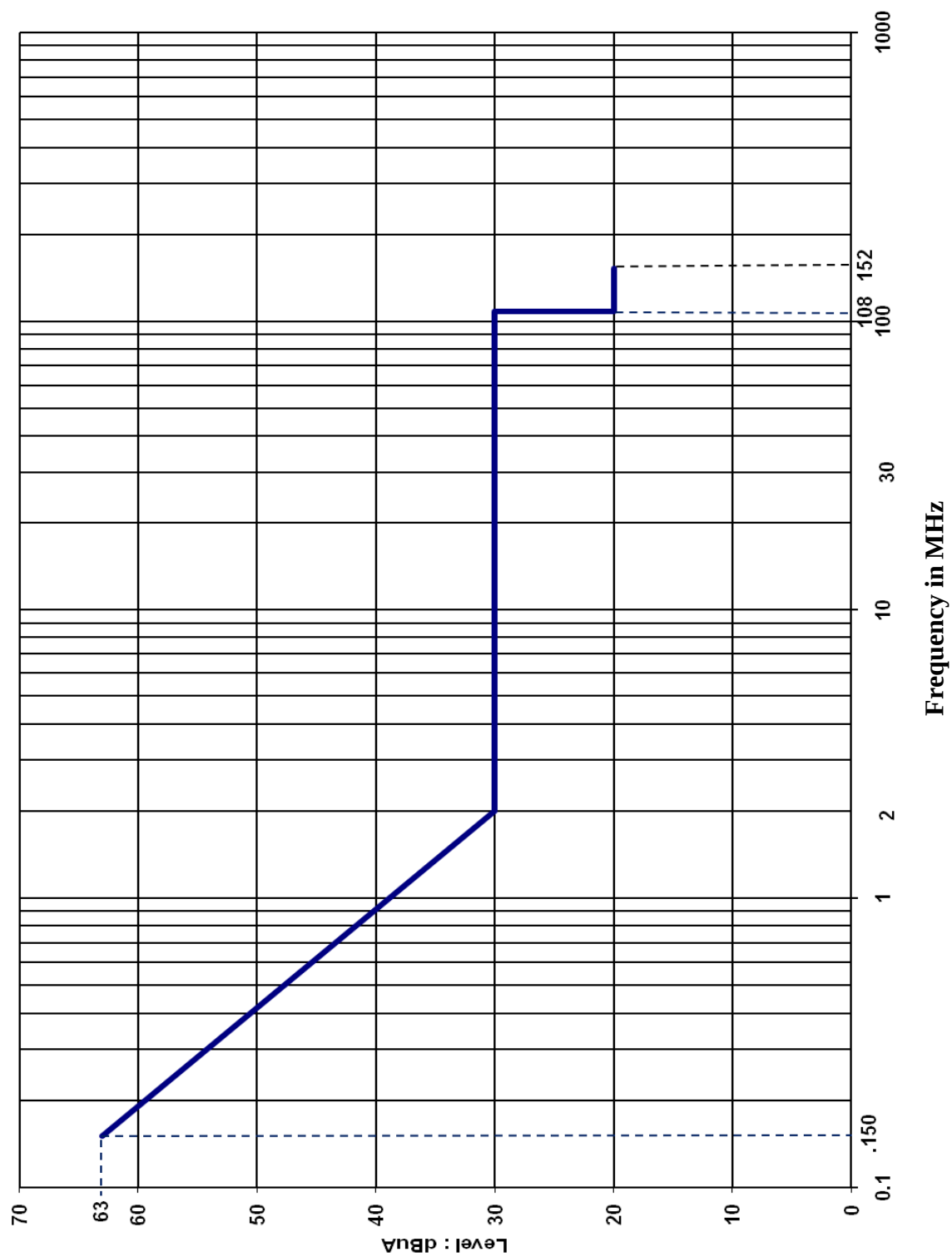
Figure 21-3 : Maximum Level of Conducted RF Interference – Category P Interconnecting Bundles and Power Lines



Curve definition : Limit Level = slope * log(freq in MHz) + intercept

Category P: F<2 MHz slope = -29.335, intercept = 28.83

Figure 21-4 : Maximum Level of Conducted RF Interference – Category Q Power Lines



Curve definition : Limit Level = slope * log(freq in MHz) + intercept
 Category P: F < 2 MHz slope = -29.335, intercept = 38.83

Figure 21-5 : Maximum Level of Conducted RF Interference – Category Q Interconnecting Bundles

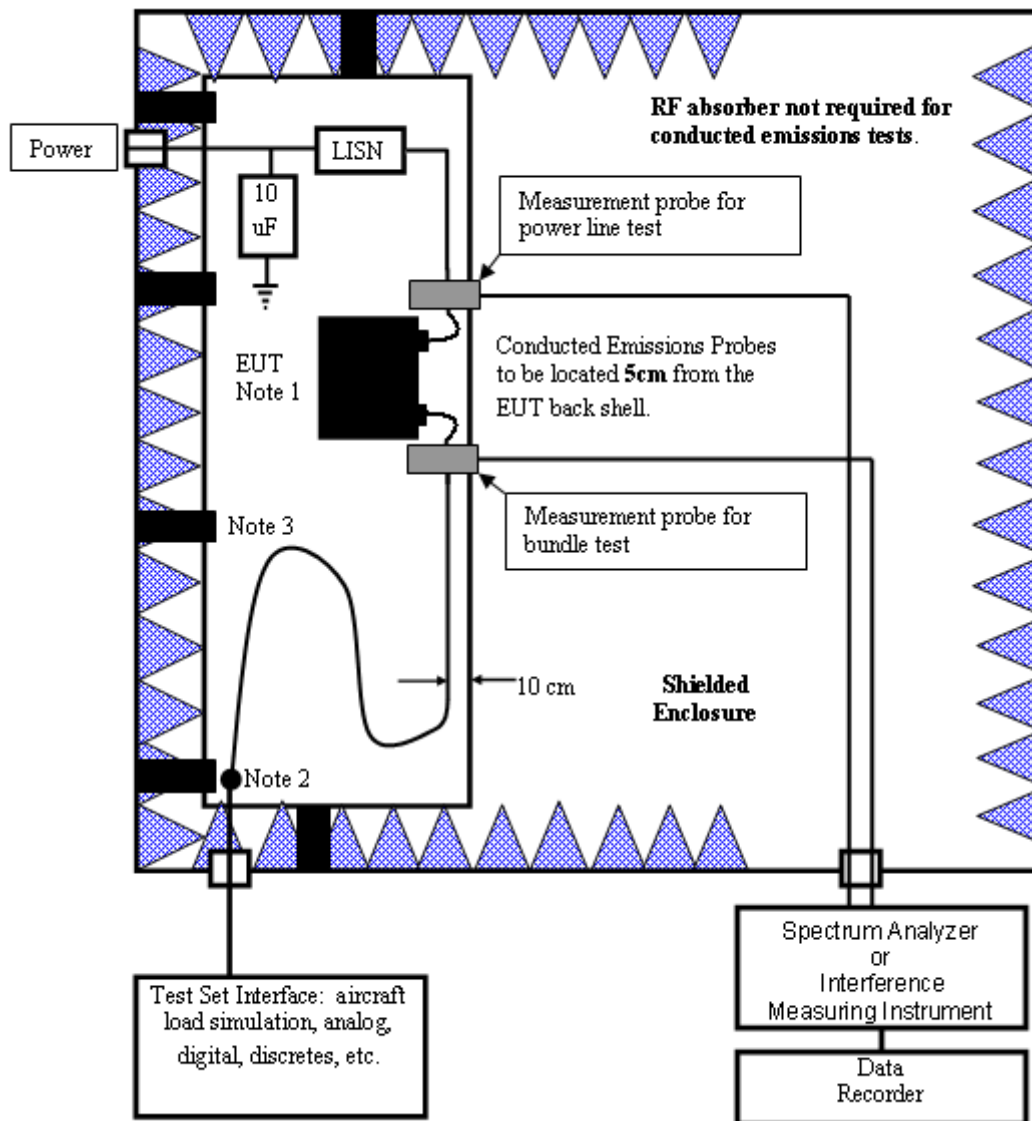
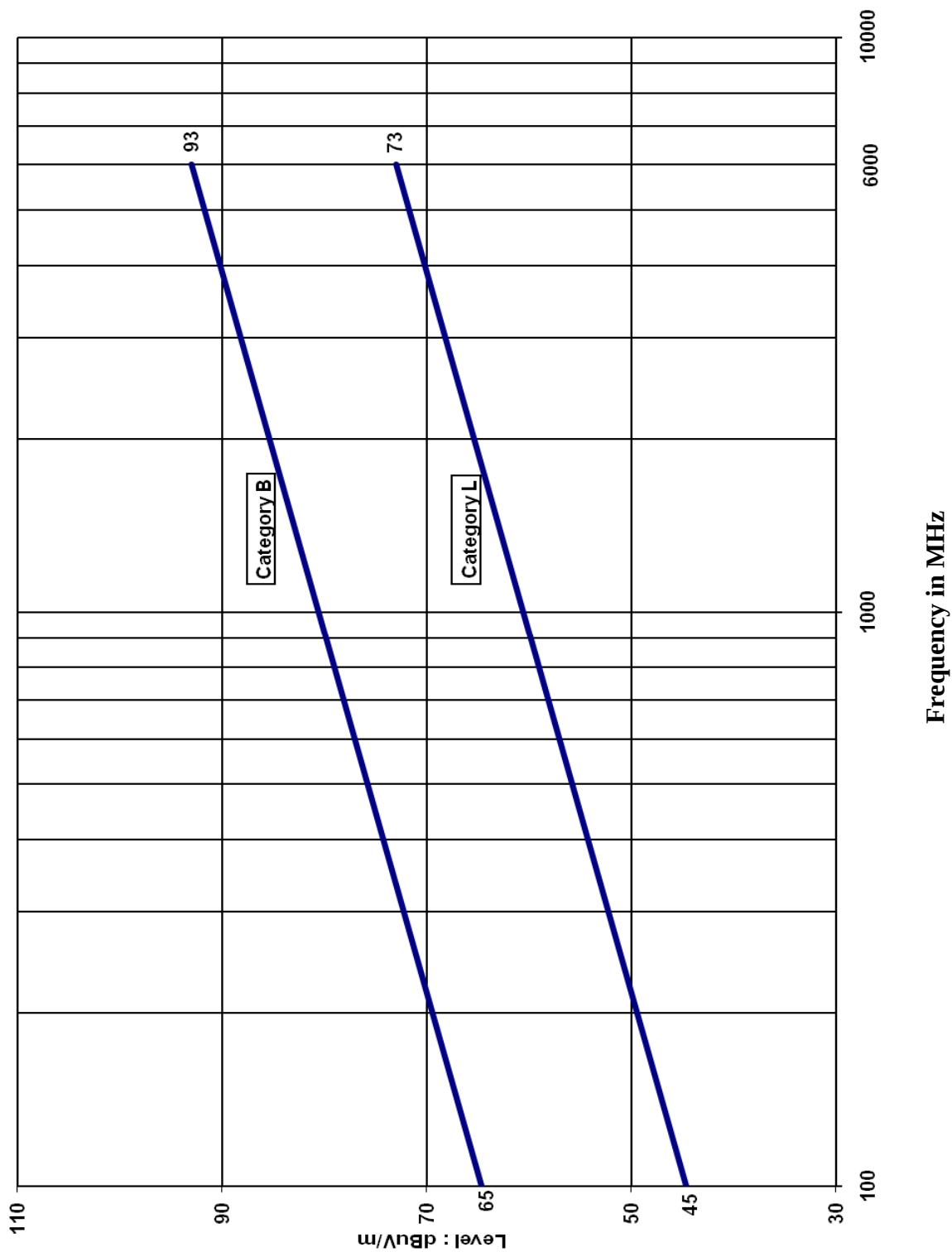


Figure 21-6 Typical Setup for Conducted RF Interference Test

Note 1 See Section 20.3 for EUT general requirements.

Note 2 End of exposed cable. Unshielded cable may be shielded from here to the wall.

Note 3 Bonding strap.



Curve definition : Limit Level = slope * log(freq in MHz) + intercept

Category B: F > 100 MHz slope = 15.965, intercept = 32.682

Category L: F > 100 MHz slope = 15.965, intercept = 12.682

Figure 21-7 : Maximum Level of Radiated RF Interference – Category B & L

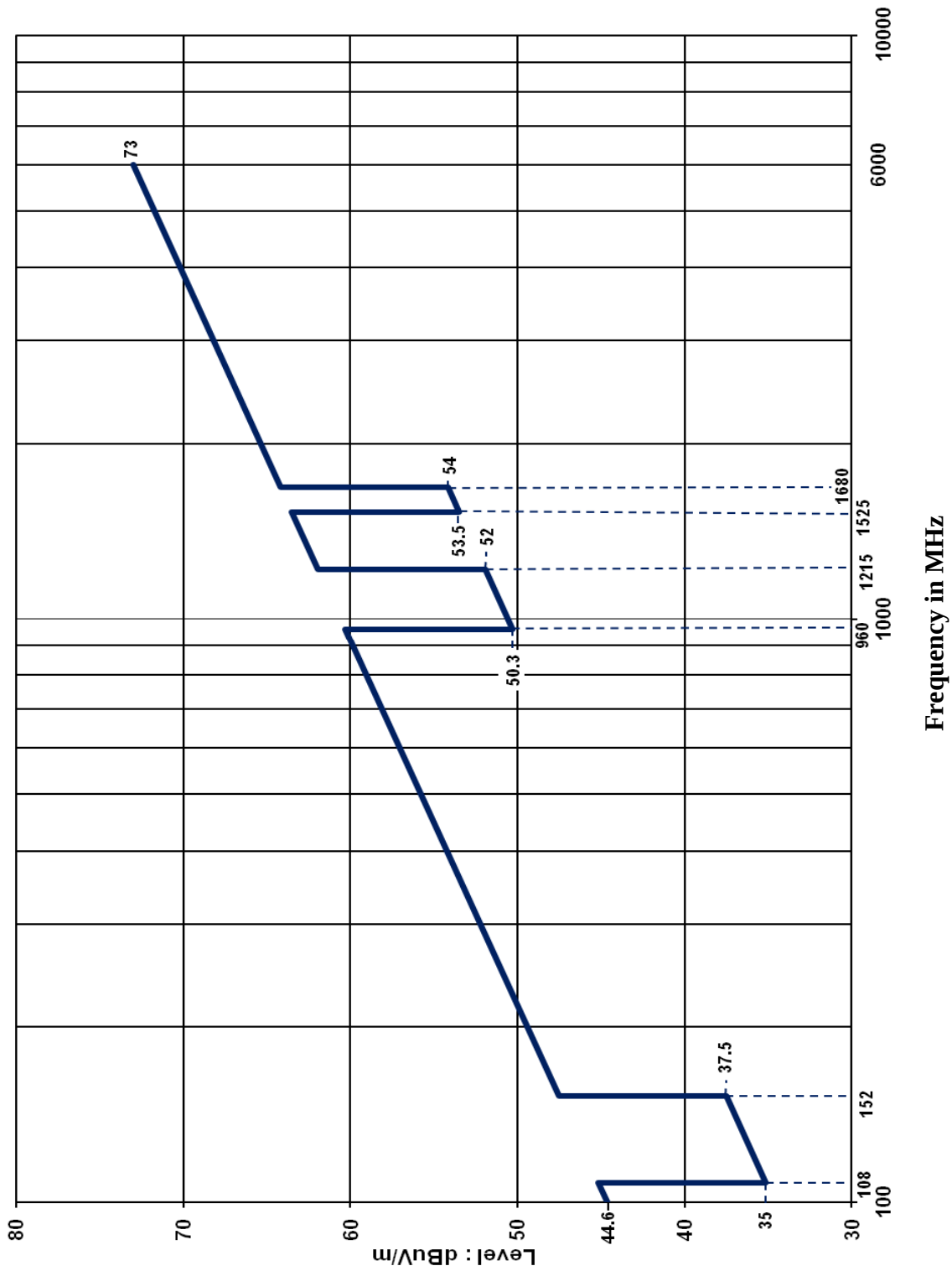
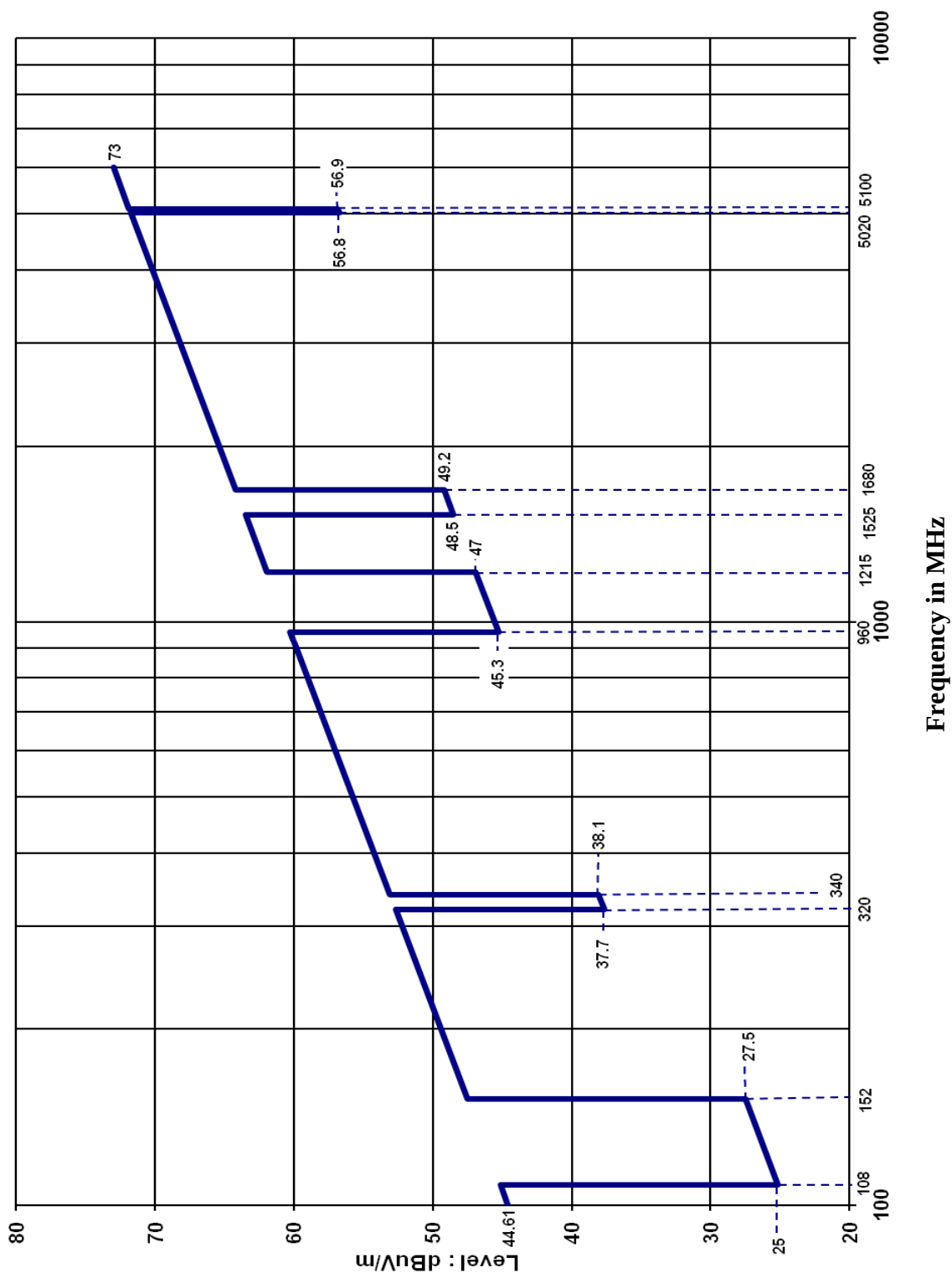
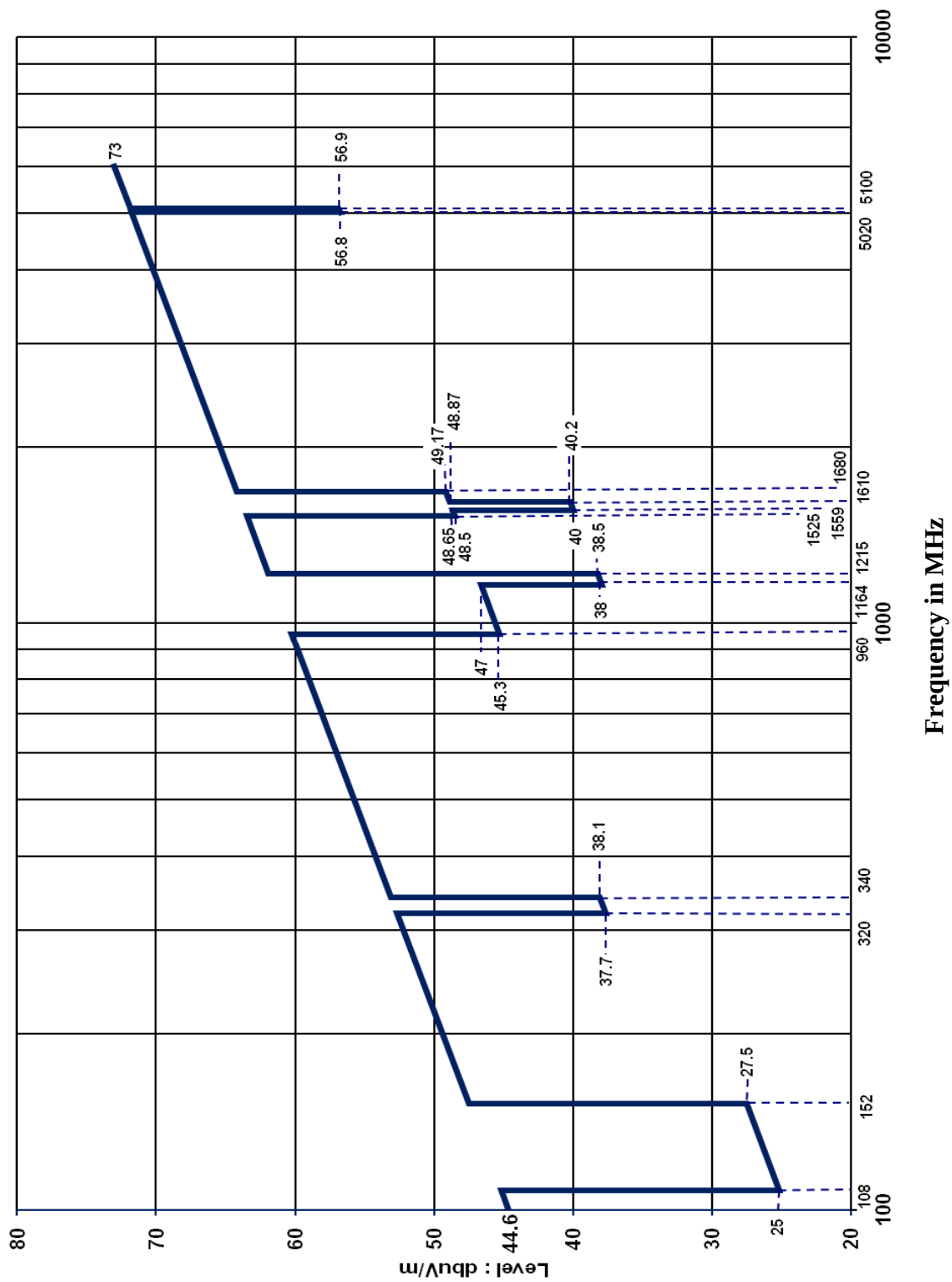


Figure 21-8 : Maximum Level of Radiated RF Interference – Category M



Curve definition : Limit Level = slope * log(freq in MHz) + intercept
 Category H: F > 100 MHz slope = 15.965, intercept = 12.682

Figure 21-9 : Maximum Level of Radiated RF Interference – Category H



Curve definition : Limit Level = slope * log(freq in MHz) + intercept
 Category P & Q: F > 100 MHz slope = 15.965, intercept = 12.682

Figure 21-10 : Maximum Level of Radiated RF Interference – Category P & Q

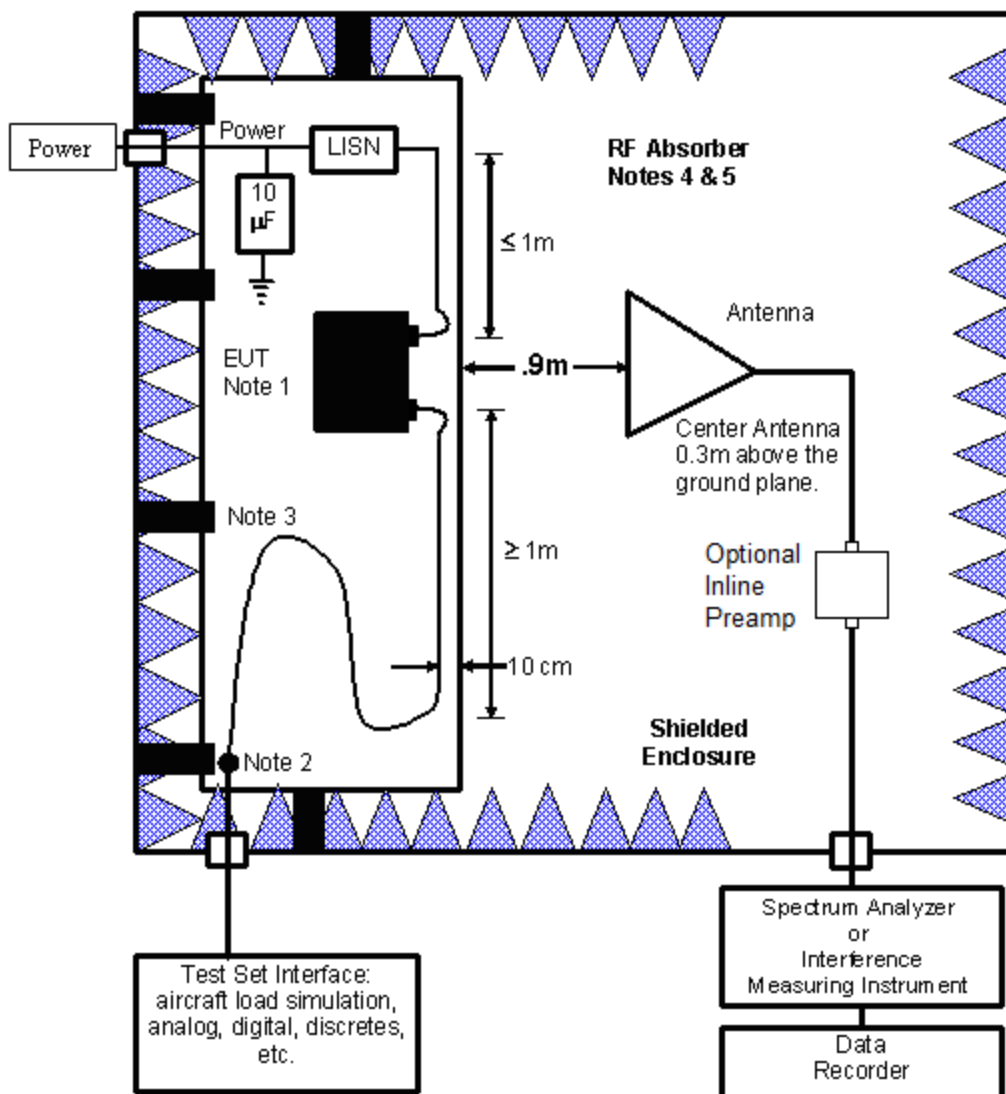


Figure 21-11 – Radiated Emissions Test Setup

- Note 1** See Section 20.3 for EUT general requirements.
- Note 2** End of exposed cable. Unshielded cable may be shielded from here to the wall.
- Note 3** Bonding strap.
- Note 4** RF absorber shall be placed above, behind, and on both sides of test setup boundary, from ceiling to ground plane. The absorber shall extend $\geq 50\text{ cm}$ in front of the ground plane.
- Note 5** RF absorber shall be placed behind the test antenna, from ceiling to floor. The distance between the absorber and the antenna shall be $\geq 30\text{ cm}$.

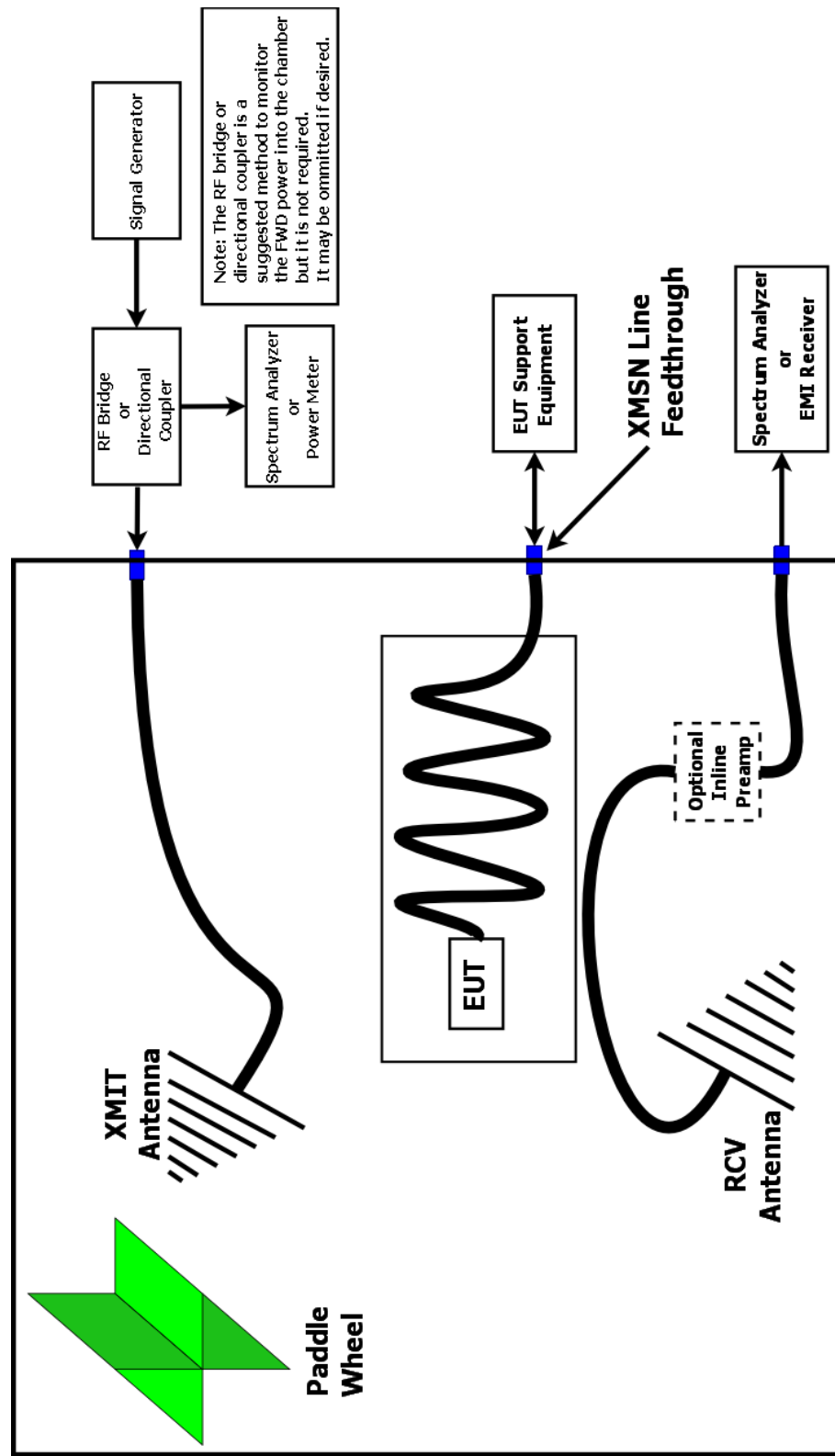


Figure 21-12 – Reverb Radiated Emissions Insertion Loss Measurement Setup

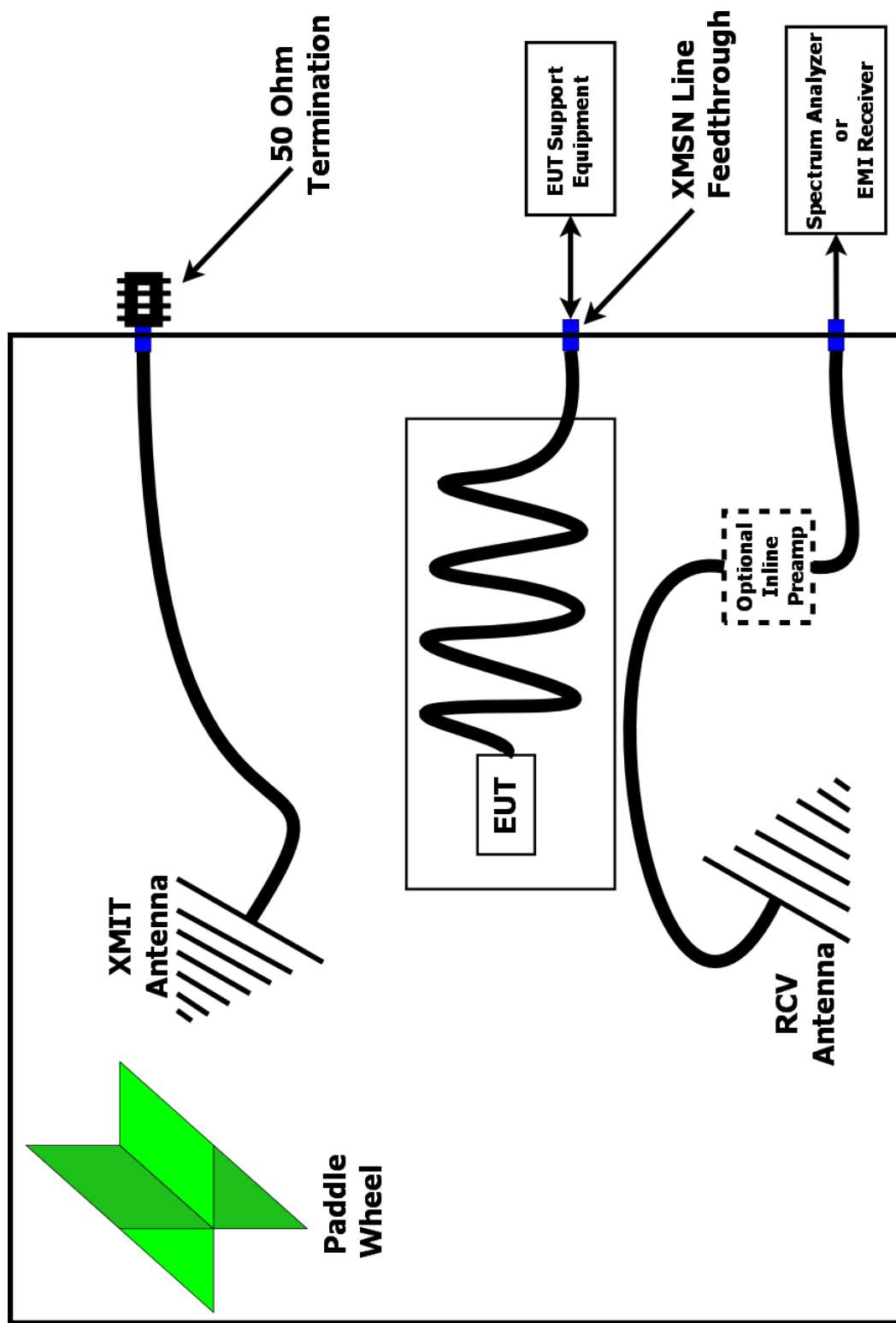


Figure 21-13 – Reverb Radiated Emissions Test Setup

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RTCA/DO-160G

**Environmental Conditions and Test
Procedures for Airborne Equipment**

User Guide to Section 21

Emission of Radio Frequency Energy

**Based on
DO-160G Section 21**

Date of Issue:
December 8, 2010

Prepared by: RTCA SC-135

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User's Guide, Appendix 21

Section 21 defines limits, test procedures and requirements. In order to properly interpret the procedures and requirements outlined in Section 21, a User's Guide is provided as an Appendix to Section 21.

The User's Guide includes rationale, guidance and background information for the environment, test procedures and requirements, guidance in applying the requirements, and lessons learned from aircraft and laboratory experience. This information should help user's understand the intent behind the requirements, should aid in tailoring requirements as necessary for particular applications and should help user's develop detailed test procedures based on the general test procedures in Section 21.

The User's Guide follows a parallel format to the main body of Section 21 for easy cross reference. Paragraph numbers corresponding to each paragraph in Section 21 are included the User's Guide. Where there is no additional information provided in the User's Guide, the paragraph header is provided but the following paragraph is left blank.

21.0 Emission of Radio Frequency Energy

21.1 Purpose of the Test

21.2 Equipment Categories

21.3 General Requirements

21.4 Conducted RF Emissions

21.5 Radiated RF Emissions

21.6 Radiated RF Emissions; Reverberation Chamber Procedure

21.6.4 Radiated RF Emissions Test

- i. During the development of the reverb technique it was noted that the limit lines originally incorporated into Section 21 were based on the directivity of a dipole. This led the working group to conclude that the assumption in Note 1 was in keeping with the original limit lines.

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 22

Lightning Induced Transient Susceptibility

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2 and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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22.0 Lightning Induced Transient Susceptibility

22.1 Purpose of Tests

These test methods and procedures are provided to verify the capability of equipment to withstand a selection of test transients defined in this section which are intended to represent the induced effects of lightning. The waveforms and levels, and the pass/fail criteria for equipment performance during the test shall be listed in the applicable equipment specification.

Two groups of tests may be used for equipment qualification. The first is a damage tolerance test performed using pin injection as described in paragraph 22.5.1. The second group, as described in paragraph 22.5.2, evaluates the functional upset tolerance of equipment when transients are applied to interconnecting cable bundles. Cable bundle tests include single stroke, multiple stroke, and multiple burst, response tests (hereafter referred to as single stroke, multiple stroke and multiple burst). Cable bundle tests can also provide an indication of damage tolerance.

Note: These tests may not cover all aspects of lightning induced interaction and effects on equipment. Additional tests such as tests of the equipment in a complete system may be required to achieve certification of a specific installation, depending upon the functions performed. For externally mounted equipment, direct effects tests may also be required. These tests are covered in Section 23 of this document.

22.2 Definitions

Cable Bundle

A group of wires and/or cables bound or routed together that connect a piece of equipment to one or more pieces of equipment comprising the system under test.

Calibration Loop

A heavy duty, low self-inductance, low resistance, single turn wire loop passed through the injection transformer to form an insulated secondary winding. It should be low enough in impedance to achieve the test level and waveform.

Core Wire

An individual wire inside a shield. The individual wire induced voltages/currents are reduced from the driven loop voltages/currents by the presence of the shield (i.e. by the shield transfer impedance).

Generator

A set of equipment (waveform synthesizer, amplifiers, couplers, etc.) that delivers a voltage or current waveform, via direct or indirect coupling to the equipment under test (EUT).

Local Ground

Any ground strap or conductor less than 1 meter in length that is connected to the equipment and the same part of airframe structure to which that equipment is installed. The ground strap or conductor would therefore be bonded to the same ground plane that the equipment is mounted to and, during a lightning strike, would be at the same structural voltage potential as the equipment.

Monitor Loop

A close fitting, single turn, wire loop wound through the injection transformer to form an insulated secondary winding. It is used to monitor the induced cable bundle or calibration loop voltage.

Multiple Burst Application

A set of transient waveforms intended to represent the induced effects of the external lightning Multiple Burst Waveform Set in aircraft wiring. The Multiple Burst Application includes an induced transient corresponding to each current pulse in the external environment. Each of the induced transients is the response to the external environment. There are three groups of twenty transients in the Multiple Burst Application.

Multiple Stroke Application

A set of transient waveforms intended to represent the induced effects of the external lightning Multiple Stroke Waveform Set in aircraft wiring. The Multiple Stroke Application includes an induced transient waveform corresponding to each stroke in the external multiple stroke environment. There are fourteen transients in the Multiple Stroke Application. The first induced transient is the response to first return stroke of the external environment and the following thirteen transients are the response to follow on or multiple return strokes of the external lightning environment.

Shield

For the purposes of this section, a shield is a conductor which is grounded to an equipment case or aircraft structure at both ends and is routed in parallel with and bound within a cable bundle. It is usually a wire braid around some of the wires or cables in the cable bundle or may be a metallic conduit, channel or wire grounded at both ends within the cable bundle. The effect of the shield is to provide a low resistance path between equipment so connected.

Shielded Cable Bundle

A cable bundle that contains one or more shields. Such cable bundles may include some unshielded wires.

Single Stroke Response

Representative wiring response to the most severe external component of a lightning strike to an aircraft.

Transfer Impedance

The ratio of the core wire open circuit voltage to the shield current

Unshielded Cable Bundle

A cable bundle that contains no shields.

22.3 Categories

The equipment manufacturer must test the equipment to the test levels and waveforms consistent with its expected use and aircraft installation.

Category designation for equipment shall consist of six characters:

- a. Pin test waveform set letter (A or B) as designated in Table 22-1.1 or Z or X.
- b. Pin test level (1 to 5) as designated in Table 22-2 or Z or X.
- c. Cable bundle single and multiple stroke test waveform set letter (C through K) as designated in Table 22-1.2 or Z or X.
- d. Cable bundle single and multiple stroke test level (1 to 5) as designated in Table 22-3 and Table 22-4 or Z or X.
- e. Cable bundle multiple burst test waveform set letter (L or M) as designated in Table 22-1.2 or Z or X.
- f. Cable bundle multiple burst test level (1 to 5) as designated in Table 22-5 or Z or X.

Category designation should, therefore, appear as follows:

B	3	G	4	L	3
Pin Test Waveform Set	Pin Test Level	Cable Bundle Single and Multiple Stroke Test Waveform Set	Cable Bundle Single and Multiple Stroke Test Level	Cable Bundle Multiple Burst Test Waveform Set	Cable Bundle Multiple Burst Test Level

In the above example, Category B3G4L3 identifies an equipment with Pin Injection test using waveform set B (Table 22-1.1), level 3 (Table 22-2) and cable bundle single and multiple stroke test with waveform set G including single stroke tests at level 4 as indicated in Table 22-3, multiple stroke tests at level 4 as indicated in Table 22-4, and multiple burst tests with Waveform Set L and test level 3 as indicated in Table 22-5. In another example B3XXXX would identify an equipment pin test with waveform set B at level 3 as indicated in Table 22-2. When no tests are performed, the category designation is XXXXXX. As shown in the above example, pin-to-case test levels might be different from the cable bundle test levels.

Figure 22-1 through Figure 22-8 define the individual waveforms associated with waveform sets A through L.

The use of Z in the waveform set designator positions indicates that either the waveform set or the test configuration (i.e. shielding, grounding) was different from that designated in Table 22-1.1 or Table 22-1.2. Similarly, a Z in the test level position indicates that the test levels applied were different from those designated in Table 22-2 through Table 22-5. For example, AZZ3Z3 indicates that pin tests were conducted at level(s) other than those designated, and the single stroke, multiple stroke and multiple burst tests were performed using an alternate waveform set or an alternate configuration at level 3. The specific test conditions and test levels shall be described in the test report.

22.3.1 Waveform Set Designators (First, Third and Fifth Characters)

Waveform sets A, C, E, G and J are applicable to equipment interconnected with wiring installed within airframes or airframe sections where apertures, not structural resistance, are the main source of induced transients as would be the case in an all-metal airframe. For the same reasons, these waveform sets can also apply to equipment in airframes composed of metal framework and composite skin panels, and to equipment in carbon fiber composite (CFC) airframes whose major surface areas have been protected with metal meshes or foils.

Waveform sets B, D, F, H and K are applicable to equipment interconnected with wiring installed within any airframe or airframe section when structural resistance is also a significant source of induced transients, (i.e., carbon fiber composite structures). In these cases the wiring is exposed to high structural voltages and redistributed lightning currents, which are represented by Waveform 5A.

Cable bundle test waveform sets E, F, J and K are applicable for equipment interconnected with shielded wiring in all cable bundles. An exception is made for equipment interconnected with shielded wiring in all cable bundles except for unshielded power wiring, in which sets E, F, J and K are still applicable to all cable bundles.

Cable bundle test waveform sets C, D, G and H are applicable for equipment interconnected with unshielded wiring in all cable bundles.

A and B are for pin injection tests.

C through F are for cable bundle single stroke tests.

G through K are for cable bundle single stroke and multiple stroke

L and M are for cable bundle multiple burst tests.

Z indicates tests other than those specified in [Table 22-1.1](#) or [Table 22-1.2](#) were conducted, such as the use of waveform set C, D, G, or H with shielded cables. For example, equipment with both shielded and unshielded cable bundles, in which waveform sets E, F, J and K are applicable to the shielded cable bundles and waveform sets C, D, G and H are applicable to the unshielded cable bundles with the noted exception for unshielded power wiring. Other examples of the applicability of the Z waveform set designator are provided in paragraph 22.5.1 and paragraph 22.5.2.

22.3.2 Test Level Designators (Second, Fourth and Sixth Characters)

Test level descriptions for internal aircraft environments are provided below with specific levels for each test waveform listed in [Table 22-2](#) through [Table 22-5](#). Levels 1 through 5 allow flexibility in the protection of equipment. The descriptions are for guidance only. Anticipated exposure of interconnecting wiring and equipment location determines the test level.

Level 1 is intended for equipment and interconnecting wiring installed in a well-protected environment.

Level 2 is intended for equipment and interconnecting wiring installed in a partially protected environment.

Level 3 is intended for equipment and interconnecting wiring installed in a moderately exposed environment.

Levels 4 and 5 are intended for equipment and interconnecting wiring installed in severe electromagnetic environments.

Z indicates tests conducted at voltage and/or current levels other than those specified in Table 22-2 through Table 22-5.

22.4 General Test Requirements

- a. Equipment Under Test - The EUT shall be set up on a ground plane and configured in accordance with the following criteria unless otherwise specified by the individual equipment specification:
 - (1) Ground Plane - A copper, brass or aluminum ground plane, at least 0.25 mm thick for copper and aluminum, 0.5 mm thick for brass, 2.5 m² or more in area with a minimum depth (front to back) of 0.75 m shall be used. When a shielded enclosure is employed, the ground plane shall be bonded to the shielded enclosure at intervals no greater than one meter and at both ends of the ground plane. It is recommended that the dc bonding resistance should be 2.5 milliohms or less.
 - (2) Shock and Vibration Isolators - If specified by the equipment manufacturer, the EUT shall be secured to mounting bases incorporating shock or vibration isolators. The bonding straps furnished with the mounting bases shall be connected to the ground plane. When mounting bases do not incorporate bonding straps, they shall not be used in the test setup.
 - (3) Electrical Bonding - Only the provisions included in the EUT design or installation instructions (e.g., bonding of enclosure, mounting base and ground plane) shall be used for bonding. The electrical bonding of equipment, connectors and wire bundles shall be representative of aircraft installations and in accordance with the equipment manufacturers' requirements for minimum performance.

Equipment intended to be grounded by means other than the bonding supplied by the installation method should be placed on an insulating mat. The test report shall describe the bonding methods employed.

- (4) External Ground Terminal - When an external terminal is available for a ground connection on the EUT, the terminal shall be connected to the ground plane to ensure safe operating conditions during the test, unless otherwise specified for these tests. The length of the connection defined in the installation instructions shall be used; if a length is not defined, use approximately 30 cm of a representative wire or strap.

These grounds should not be included as a parallel current path with the cable bundle under test unless this is otherwise specified in the equipment installation instructions. If present at the unit under test during ground injection tests, these grounds should either be connected to the EUT chassis or the injection has to be applied at the remote end.

- (5) Interconnecting Wiring/Cable Bundles - For cable bundle tests, all EUT interconnecting wiring (e.g., shielded wires, twisted wires, etc.), cable bundles and RF transmission lines shall be in accordance with the applicable installation and interface control drawings or diagrams.

Cables shall be bundled in a manner similar to that of aircraft installations and the lowest point of the cable bundle supported at a height of 50 mm above the ground plane unless greater heights have been specified as more representative of the aircraft installation (and recorded in the test report). The supporting material must be non-absorptive, non-conductive, and non-reflective. For complex cable bundle configurations, all cable bundles and interconnected loads should be kept separated from each other as much as practical to minimize coupling effects between cables.

Unless otherwise specified, the cable bundle shall be at least 3.3 m. When the length of an interconnecting cable bundle is greater than the test bench, the cable bundle should be arranged with the excess length zig-zagged at the back of the test bench approximately 50 mm above the ground plane.

Some special installations may require very long cable bundle lengths which cannot be accommodated on the test bench; therefore, the recommended maximum length of the interconnecting cable bundles for these tests should not exceed 15 m. The exception to this limitation is where cable bundle lengths are matched or specified to a particular length for phase match or similar reasons.

- (6) Power Leads - For cable bundle tests, power and return leads normally bundled with the control/signal leads shall remain in the cable bundle and only be separated from the bundle just prior to the cable bundle exiting the test area. These leads shall then be connected to Line Impedance Stabilization Networks (LISNs). See paragraph 22.4b (2).

When the actual aircraft cable bundle configuration is unknown or when power and/or return leads are normally routed separately from the control/signal leads, the power and return leads should be broken out of the cable bundle near the connector of the EUT and run separately to the LISNs. Under these conditions, the length of the leads to the LISNs shall not exceed 1.0 m unless otherwise specified in the applicable equipment specification.

When the return lead is a local ground (less than 1 meter in length), this lead may be grounded directly to the test bench, in accordance with the applicable installation and interface control drawings or diagrams.

- (7) Interface Loads and Support Equipment - Cable bundle tests ideally should be performed on fully functioning equipment. EUTs should be suitably loaded with actual interface equipment.

Where the interface equipment must be simulated, the simulated electrical, electronic and/or electromechanical characteristics of the loads should be representative of the aircraft installation. To avoid altering the voltage and current distributions in the cable bundles, the electrical/electronic loads should simulate the actual load line-to-line and line-to-ground impedances (including stray capacitance and non-linear devices) under lightning conditions.

Care should be taken that any test configuration, simulated load or monitoring equipment does not alter the susceptibility or immunity of the EUT. The support equipment may require protection from the effects of the applied transients in order to avoid upset or damage.

- (8) Dummy Antennas or Loads - For the purpose of this test, antenna cables may be terminated in a load equal to the cable characteristic impedance, or a dummy antenna. The dummy antenna, if used, shall be shielded and be designed to have electrical characteristics closely simulating the in-service antenna. It shall also contain electrical components normally used in the antenna, such as filters, crystal diodes, synchros and motors.
- b. Test equipment - These shall be set up and configured in accordance with the following criteria:
- (1) Bonding - Test equipment shall be bonded and grounded to minimize ground loops and ensure personnel safety. When high current levels are to be applied to cable bundles, care shall be exercised to ensure that these currents are safely transferred from the shields to the wall of the shielded enclosure or that adequate bonding and shielding is provided outside the shielded enclosure to minimize risk to personnel.
 - (2) Line Impedance Stabilization Network - A LISN shall be inserted in each primary power input and return line. Power return lines locally grounded in the aircraft installation do not require a LISN. The LISN case shall be bonded to the ground plane. When LISNs with self resonances above 10 kHz are used (such as standard 5uH LISN), capacitors shall be inserted at each LISN power input terminal as shown in [Figure 22-17](#) or [Figure 22-19](#) for the entire test. The RF measurement port of the LISN shall be terminated into 50 ohms for all tests. The input impedance characteristic of the LISN is shown in [Figure 22-9](#). [file:///C:/Documents and Settings/HMoses/Local Settings/Temporary Internet Files/Content.Outlook/PP2MZEW5/AE-2/Temp/Local Settings/Documents and Settings/ajmeyer/Local Settings/Documents and Settings/ajmeyer/Local Settings/Documents and Settings/ajmeyer/Local Settings/Temp/2006 San Diego/WG31 Comments/Users Guide/Homework/UG 011.doc](file:///C:/Documents%20and%20Settings/HMoses/Local%20Settings/Temporary%20Internet%20Files/Content.Outlook/PP2MZEW5/AE-2/Temp/Local%20Settings/Documents%20and%20Settings/ajmeyer/Local%20Settings/Documents%20and%20Settings/ajmeyer/Local%20Settings/Documents%20and%20Settings/ajmeyer/Local%20Settings/Temp/2006%20San%20Diego/WG31%20Comments/Users%20Guide/Homework/UG%20011.doc)
 - (3) Measurement Probes and Injection Transformers - Probes shall have the necessary power, bandwidth and dynamic range capabilities to reproduce the test waveform(s). Waveform 3 tests require the use of current measurement probes with electrostatic shielding.
- c. Data Required In Test Report - The test report shall include the following test setup and data items.
- (1) Cable Configuration(s) - The length of each cable bundle, types of wiring, shielding and shield terminations (including individual as well as overall shields), and the wiring diagram of the test harness.

- (2) Test Setups - Schematic or block diagrams or photographs of each test setup including layout of cable bundles, placement of transient injection and measurement probes and EUT bonding methods.
- (3) EUT Operating Mode(s) - The mode(s) of operation used during cable bundle tests.
- (4) Load(s) - A description of all loads, either actual or simulated. Simulated loads shall identify the extent of impedance simulation both line-to-line and line-to-case (ground).
- (5) Test Waveforms and Levels - Calibration/verification oscillograms of each test waveform and level.
- (6) Applied Transients - For each waveform and polarity applied at an injection point, record one sample of the voltage and current waveforms.
- (7) Pass/Fail Criteria - A description of the pass/fail criteria.
- (8) Test Results - The results of the test and any responses that do not meet the pass/fail criteria.

22.5 Test Procedures

Pin injection tests are primarily for damage assessment and involve the injection of transients directly into EUT interface circuits.

Cable bundle tests determine whether functioning equipment will experience upset or component damage when the equipment and its interconnecting wiring are exposed to the applied transients. The test methods and procedures are applicable to configurations composed of the EUT, interconnecting cable bundle(s) and load(s).

EUTs included in complex systems where various cable bundles are exposed to widely different environments may require different test levels on different cable bundles, requiring a Z category designator (see paragraph 22.3).

WARNING

The transient generators used in these tests produce lethal voltage and current levels. Exercise all operational safety precautions to prevent injury or death of test and support personnel.

22.5.1 Pin Injection Tests

Pin injection testing is a technique whereby the chosen transient waveform(s) is applied directly to the designated pins of the EUT connector, usually between each pin and case ground. This method is used for assessing the dielectric withstand voltage or damage tolerance of equipment interface circuits.

- a. Pin injection testing shall be used on the EUT, however a dielectric withstand voltage method (hi-pot) may be used when the EUT is a simple electrical or electromechanical device that is isolated from case and local airframe ground. The Hi-pot test is not applicable for any EUT containing electronic components. The dielectric withstand voltage test level shall be at least the peak amplitude of a level in Table 22-2. When testing pins which normally have a bias voltage, i.e. power line inputs or other sources, this voltage must be added to the peak test voltage of Table 22-2. This satisfies the intent of the pin test requirement however the category must be marked as Z. Identification of the simple device(s), and a description of the test shall be provided in the test report.
- b. Power shall be applied to the EUT except when the EUT has only passive components (e.g. electromechanical devices, temperature probes, hydraulic valves, etc.) and the presence of operating voltages and associated currents is not a factor in component failure.
- c. When testing a unit with power applied, a suitable means must be used to ensure that the transient generator does not produce excessive loading of power supply or signal lines. In addition, when testing input power lines with power applied to the unit, some form of blocking device is necessary to ensure that the applied transients will be directed to the interface of the equipment and not into the power supply or any other load.
- d. For pin injection testing, waveform 3 shall be applied at 1.0 MHz ($\pm 20\%$). It is not allowed to test both polarities of Waveform 3 using one polarity setting. The waveform must be applied with a positive first half-cycle and then reversed for a negative first half-cycle.
- e. In order to ease possible testing difficulties, pin tests under excitation of input power may also be accomplished by cable induction testing using the appropriate pin test waveforms and levels (Calibrated per [Figure 22-11](#) and tested per [Figure 22-14](#)). Any shields on primary power lines being tested using this method shall be removed.
- f. Groups (Four or more) of EUT circuits (pins) with the same circuit design for both protection and operation may be qualified by testing three representative pins of each group. The remaining pins in the group are qualified by similarity.
- g. Multiple pins may be tested simultaneously if the applied test voltage amplitude and waveshape remains within the tolerances of the calibration open circuit voltage amplitude and waveshape. This is applicable only for input / output that are high impedance even under lightning conditions (and during tests).

- h. When the remote load impedance characteristics between the remote pin and the airframe ground at that extremity (including the fact that the dielectric strength characteristics of the remote load can tolerate the open circuit voltage of the transient generator) are specified in the equipment installation requirements, that impedance may be inserted in series between the generator and EUT provided that the load does not employ a protective device that would short out the load impedance. This remote load shall not be included during the generator calibration. To account for cable characteristic impedance effects, the maximum inserted series impedance shall be limited to 75 ohms during Waveform 3 tests. When the remote load impedance to airframe ground is inserted in the test circuit, the load shall consist of a non-inductive resistor with lead lengths as short as possible. If a load resistor is inserted, the category designator shall be Z. The test method, remote load impedance and dielectric strength shall be noted in the qualification test form and test report.
- i. When the signal ground is connected to the structure outside the equipment in the real installation, it shall be also connected to the ground during laboratory tests. See [Figure 22-13](#), Note 4. Warning: In some designs a single protection device may be used to protect multiple interfaces. In such designs the single pin to case test might not account for transients appearing on multiple interfaces at the same time. An assessment of the protection device rating and/or test method may be required.

22.5.1.1 Procedures - Generator Calibration

The calibration set-up is to be as shown in [Figure 22-10](#). For the pin injection tests with power on, in order to avoid shorting EUT currents through the generator low source impedances, a current blocking component should be included at the output of the pin test generator. This current blocking component is to be included as part of the calibration setup as shown in [Figure 22-10](#).

When testing power pins with external power applied, the calibration setup of [Figure 22-11](#) or [Figure 22-12](#) would be applicable. In these setups, a means must be provided to bypass the power supply impedances to ensure that the transient waveform can be achieved at the calibration point. This bypass circuit also serves to protect the power supply. Note that power should not be applied while performing the following calibration procedure.

- a. Adjust the transient generator such that the applicable open circuit voltage (V_{oc}) waveform parameters identified in [Figure 22-4](#) to [Figure 22-6](#) and level of [Table 22-2](#) are attained within specified tolerances at the calibration point shown in [Figure 22-10](#), [Figure 22-11](#) or [Figure 22-12](#) as applicable.
- b. Record the V_{oc} waveform parameters and level, waveform polarity and the generator setting so the test level can be repeated during testing.
- c. At the same generator setting, measure the short circuit current (I_{sc}) as shown in [Figure 22-10](#), [Figure 22-11](#), or [Figure 22-12](#) as applicable. Verify that the I_{sc} level of [Table 22-2](#) is attained within specified tolerances and that the general waveshape is retained.
- d. Record the I_{sc} waveform parameters, level, and waveform polarity.

22.5.1.2 Procedures - Test Sequence

- a. As illustrated in Figure 22-13 or for power pins, Figure 22-14 or Figure 22-15, connect the calibration point to a designated pin of the EUT by means of a short, low inductance lead.
- b. If applicable, apply power to the EUT.
- c. At the generator setting previously established in paragraph 22.5.1.1 apply ten individual transients to the selected pin. Monitor the waveform of each applied transient for signs of unexpected changes in the waveshape. The maximum time between application of each transient shall be no greater than 1 minute.
- d. Repeat step c for each designated pin in each connector of the EUT.
- e. Reverse the transient generator polarity; repeat the generator calibration, and repeat steps a through d.
- f. Repeat the generator calibration and test sequence for each test waveform.
- g. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

22.5.2 Cable Bundle Tests

Cable bundle testing is a technique where transients are applied by cable induction or ground injection. These methods are used to verify that aircraft equipment can withstand the internal electromagnetic effects produced by the external lightning environment without experiencing functional upset or component damage. In either method, the test must be performed on fully configured and functioning equipment complete with interconnecting cable bundles and interface loads. This test requirement is satisfied by applying the specified waveforms and limits to interconnecting cable bundle(s) individually or simultaneously.

- a. All wires in a bundle from a single connector shall be tested together in order to claim a particular category or the waveform set designation must be Z. The only exception is power lines. If a power line is routed separately from the bundle then it has to be tested separately. In this case the core wire current need not exceed the corresponding pin test short circuit current level as presented in Table 22-2. The “corresponding pin test short circuit current level” shall be the same as the cable bundle test level used. For waveforms 1 and 2 use the waveform 4/1 short circuit current value. Example: For category A2J3L3 the waveform 1 short circuit current is 60 amps on the core wire (not 25 amps). If bundles are segregated based on where the wires are routed and tested to different levels, the designation must be Z.
- b. For the purposes of multiple stroke and multiple burst testing, the effect of random spacing is achieved through the timing of the application of the individual pulses and bursts in the sets of transients. See Figure 22-7 and Figure 22-8.
- c. Normally cable bundle tests are done with all shields that are present in the cable bundle connected as it is installed in the aircraft installation. If the shields off test method is used, the category designator shall be Z for the cable bundle test waveform set. The test level designator shall reflect the actual level injected on the core wires.

- d. The cable bundle single stroke test may be combined with the multiple stroke test. In this case the test level of the first transient of the multiple stroke test application is replaced with the single stroke test level provided in Table 22-3.
- e. For cable bundle tests, waveform 3 is applied at 1.0 MHz ($\pm 20\%$) and 10 MHz ($\pm 20\%$). It is not allowed to test both polarities of Waveform 3 using one polarity setting. The waveform must be applied with a positive first half-cycle and then reversed for a negative first half-cycle.
- f. Waveform 1 may be applied by using either the test method in paragraph 22.5.2.1 (Cable Induction Tests) or paragraph 22.5.2.2 (Ground Injection Tests).
- g. Under each waveform, V_T represents the test voltage level in Volts, and I_T represents the test current level in Amperes. V_L (Volts) and I_L (Amperes) represent limits intended to prevent over-stressing the EUT beyond requirements. A test is always acceptable if the test level is reached before the limit level. The following criteria applies when the limit level is reached prior to the test level:
- h. Waveforms 2, 3 and 4 are defined as voltage waveforms. When a test voltage level (V_T) is specified as Waveform 2, 3, or 4, this is the waveform that should ideally exist on the cable bundle but must be produced during generator performance verification when measured as shown in Figure 22-16 or Figure 22-18. If the specified test voltage waveform is achieved during the test and is within the tolerance shown in Figures 22-2, Figure 22-3 or Figure 22-4, no generator performance verification is required. The peak voltage level shall be measured on the cable bundle as shown in Figure 22-17 or Figure 22-19. When monitoring the current limit (I_L) associated with Waveform 2, 3 or 4 test levels (V_T), the current waveforms shall be as follows:
 - (1) For Voltage Waveform 2 tests:

If the current test limit is reached before the voltage test level and the generator produced a Waveform 1 during performance verification, then the test is acceptable. This is the expected relationship between Waveforms 1 and 2. If the generator could not produce a compliant Waveform 1 during verification then a Waveform 1 current test is required. In this situation, the waveform set designator shall be Z.
 - (2) For Voltage Waveform 3 tests:

The voltage and current waveshapes are the same therefore the test is acceptable if either the test level or test limit is reached.
 - (3) For Voltage Waveform 4 tests:

If the current test limit is reached before the voltage test level and the generator produced a current waveform that has equal to or longer rise (T1) and decay times (T2) than the voltage test waveform during performance verification, then the test is acceptable. Shorter duration current waveforms are not acceptable during performance verification. If the generator could not produce a compliant current waveform during verification then a Waveform 5A current test is required. In this situation, the waveform set designator shall be Z.

(4) Waveform 5A may be defined as a voltage waveform.

Although Waveform 5A is defined as a current waveform, the waveshape may also be used for a voltage waveform when the test method specifies lifting the wire shields for direct core wire pulsing. Waveform 5A may be defined as a voltage test level. This is the waveform that must be produced during generator performance verification when measured as shown in [Figure 22-16](#) or [Figure 22-18](#). The peak voltage level shall be measured on the cable bundle as shown in [Figure 22-17](#) or [Figure 22-19](#). For this case, the appropriate test level (V_T) of Waveform 4 of Table 22-3 with the Waveform 5A waveshape shall be used. The category shall then be labeled as Category Z.

- i. Waveforms 1, 5A, 5B and 6 are defined as current waveforms. When a current test level (I_T) is specified as Waveform 1, 5A, 5B, or 6 this is the waveform that should ideally exist on the cable bundle, but must be produced during generator performance verification when measured as shown in [Figure 22-16](#) or [Figure 22-18](#). If the specified test current waveform is achieved during the test and is within the tolerance shown in [Figure 22-3](#) or [Figure 22-4](#), no generator performance verification is required. The peak current level shall be measured on the cable bundle as shown in [Figure 22-17](#) or [Figure 22-19](#). When monitoring the voltage limit (V_L) associated with Waveform 1, 5A, 5B or 6 current test levels (I_T), the voltage waveforms shall be as follows:

(1) For current Waveform 1 tests:

If the voltage limit is reached before the current test level and the generator produced a voltage waveform with a risetime (T_1) shorter than Waveform 1 T_1 and a duration (T_2) longer than Waveform 2 during performance verification, then the test is acceptable. If the generator could not produce such a compliant voltage waveform during verification then a Waveform 2 voltage test is required. In this situation, the waveform set designator shall be Z.

(2) For Current Waveform 5A or 5B tests:

If the voltage limit is reached before the current test level and the generator produced a voltage Waveform risetime (T_1) shorter than Waveform 5 T_1 but not shorter than Waveform 4 T_1 during performance verification, then the test is acceptable. If the generator could not produce such a compliant voltage waveform during verification then a Waveform 4 voltage test is required. In this situation, the waveform set designator shall be Z. In certain situations related to airframe design and wiring layout, equipment may be exposed to longer duration waveforms such as Waveform 5B (see [Figure 22-5](#)). Tests conducted under these conditions shall be given designator Z.

(3) For Current Waveform 6 tests:

Waveform 6 is used to address multiple burst requirements for EUTs that utilize low impedance cable bundle installations. Waveform 6 should ideally exist on the cable bundle but must be produced during generator performance verification when measured as shown in [Figure 22-6](#). If the specified test current waveform is achieved during the test and is within the tolerance shown on [Figure 22-6](#), no generator performance verification is required. The peak current level shall be measured in the cable bundle as shown in [Figure 22-17](#) or [Figure 22-19](#). When monitoring the voltage limits (V_L), associated with Waveform 6 test levels (I_T); if the voltage limit is reached before the current test level and the generator ratio of open circuit voltage to short circuit current is less than 15 ohms, then the test is acceptable.

If the generator does not meet this criterion, then a Waveform 3 multiple burst test is required.

22.5.2.1 Cable Induction Tests

The procedures outlined in the following paragraphs are applicable for Single Stroke, Multiple Stroke and Multiple Burst tests. Cable induction is the recommended procedure for the pulse waveforms 1, 2, and 3. Use of this application technique with other waveforms is acceptable provided that the waveform calibration procedure per paragraph 22.5.2.1.1(b) can be achieved in the calibration loop of the injection transformer. Testing of local grounds is not required. Local grounds are not to be included in the bundle under test.

22.5.2.1.1 Procedures - Generator Performance Verification

- a. Connect the transient generator to the primary inputs of the injection transformer (see Figure 22-16).
- b. For each generator, at the designated test level, record the voltage waveform with the calibration loop open and the current waveform with the calibration loop shorted. Verify the relevant test level and waveshape (V_T or I_T) shown in Figure 22-1, Figure 22-2, Figure 22-3, or Figure 22-6. It is not necessary for the test generator to produce the associated voltage or current limit level and waveshape.
- c. For the multiple stroke and multiple burst tests, also verify the applicable pulse patterns and timing identified in Figure 22-7 and Figure 22-8.

22.5.2.1.2 Procedures - Test Sequence

- a. Configure the EUT, support equipment and interconnecting cable bundles as shown in Figure 22-17 with the injection transformer around the cable bundle under test. If the shield disconnect test method option described in paragraph 22.5.2 is being utilized, disconnect the shields.
- b. Connect the current and voltage monitoring probes to an oscilloscope. For uniformity of test results, the probe positions should be as close as possible to those shown.
- c. Apply power to the EUT and configure it in the selected operating mode(s). Verify proper system operation as described in the applicable equipment specification.
- d. While applying transients, increase the generator setting until the designated test level (V_T or I_T) or the limit level (V_L or I_L) is reached. Adjustments shall be made in the generator settings and/or injection transformer configuration as necessary to enable the required test voltage (V_T) or current (I_T) level to be achieved in the tested cable, unless the corresponding limit current (I_L) or voltage (V_L) levels are reached first. Generator performance shall then be re-verified if changes are made to the injection transformer configuration. Record the waveforms. If V_L or I_L is reached before V_T or I_T , the test shall be reevaluated to determine if another generator and/or waveform set is required. When measuring voltage or current waveform levels, short duration spikes or high frequency noise due to instrument noise, switching transients, or loading effects shall be ignored.

- e. For the Single Stroke test, at the generator setting established in step d, apply a minimum of ten transients while monitoring the operation of the EUT. The maximum time between application of each Single Stroke transient shall be no greater than 1 minute.
- f. For the Multiple Stroke test, at the generator setting established in step d, apply a minimum of ten multiple stroke applications while monitoring the operation of the EUT. The maximum time between application of each Multiple Stroke transient shall be no greater than 5 minutes.
- g. For the Multiple Burst test, at the generator setting established in step d, apply a multiple burst application every 3 seconds (3 seconds between the start of each set of three bursts) continuously for at least 5 minutes. Longer durations may be specified in the applicable equipment specification.
- h. Repeat steps d through g for each mode of EUT operation to be tested.
- i. Reverse the transient generator polarity; repeat the generator performance verification, and repeat steps b through h.
- j. Repeat steps b through i for each cable to be tested.
- k. Repeat the generator performance verification and steps b through j for each waveform applied.
- l. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

22.5.2.2 Ground Injection Tests

The procedures outlined in the following paragraphs are applicable for Single Stroke and Multiple Stroke tests. Ground injection is the recommended procedure for the pulse waveforms 4 and 5A. Use of this application technique with waveforms 1 and 2 is acceptable provided that the waveform calibration procedure per paragraph 22.5.2.2.1 can be achieved at the injection point.

Equipment external ground terminals, chassis ground wires and power return leads, which are connected to the ground plane locally in accordance with the applicable installation/interface control drawings, must be isolated from the ground plane during this test. In addition, if the power leads are routed separately from the main signal bundle, it may be necessary to insert AC series impedance (in addition to the LISN) in the power bundle to ensure that the proper signal bundle test levels are achieved.

The intent of this test is to achieve the applicable test level in each cable bundle (as shown in Figure 22-19), therefore tests may need to be conducted at more than one injection point. The test methodology can be different for a voltage or current test.

A voltage test is valid when the voltage test level is achieved between the EUT and the ground plane. For the voltage test, if the current limit in any one cable bundle is reached before the voltage test level, then there are two options. (1) Increase the output of the generator to reach the voltage test level or current limit in each wire bundle, with the risk of exceeding the current limit in an individual wire bundle or (2) perform a test on each cable bundle individually.

A current test is valid when the current test level is reached on each cable bundle, (with the understanding that the current test level on an individual wire bundle may be exceeded) or the voltage limit is reached between the EUT and the ground plane.

22.5.2.2.1 Procedures - Generator Performance Verification

- a. For each generator, at the designated test level, record the voltage waveform with the calibration loop open and the current waveform with the calibration loop shorted as shown in [Figure 22-18](#). Verify the relevant test level and waveshape (V_T or I_T) shown in [Figure 22-4](#) or [Figure 22-5](#). It is not necessary for the test generator to produce the voltage or current limit level and waveshape.
- b. For the multiple stroke and multiple burst tests, also verify the applicable pulse patterns and timing identified in [Figure 22-7](#) and [Figure 22-8](#).

22.5.2.2.2 Procedures - Test Sequence

- a. The general requirements of paragraph 22.4 shall apply to this test setup except that the case and all local grounds or returns at the transient injection point (EUT or a load) shall be insulated from the ground plane and connected to the equipment case. The insulator used between the case and ground plane must be capable of withstanding the maximum applied test voltage.
- b. Configure the EUT, support equipment and interconnecting cable bundles as shown in [Figure 22-19](#) with the transient generator connected between the EUT case and ground plane. If the shield disconnect test method option described in paragraph 22.5.2 is being utilized, disconnect the shields.
- c. Connect the applicable current and voltage monitoring probes to an oscilloscope.
- d. Apply power to the EUT and configure it in the proper operating mode(s). Verify proper system operation as described in the applicable equipment specification.
- e. While applying transients, increase the generator setting until the designated test level (V_T or I_T) or the limit level (V_L or I_L) is reached. Adjustments shall be made in the generator settings and/or injection transformer configuration as necessary to enable the required test voltage (V_T) or current (I_T) level to be achieved in the tested cable, unless the corresponding limit current (I_L) or voltage (V_L) levels are reached first. Generator performance shall then be re-verified if changes are made to the injection transformer configuration. Record the waveforms. If V_L or I_L is reached before V_T or I_T , the test shall be reevaluated to determine if another generator and/or waveform set is required. When measuring voltage or current waveform levels, short duration spikes or high frequency noise due to instrument noise, switching transients, or loading effects shall be ignored.

- f. For the Single Stroke test, at the generator setting established in step e, apply a minimum of ten transients while monitoring the operation of the EUT. The maximum time between application of each Single Stroke transient shall be no greater than 1 minute.
- g. For the Multiple Stroke test, at the generator setting established in step e, apply a minimum of ten events while monitoring the operation of the EUT. The maximum time between application of each Multiple Stroke transient shall be no greater than 5 minutes.
- h. Repeat steps e through g for each mode of EUT operation to be tested.
- i. Reverse the transient generator polarity; repeat the generator performance verification, and repeat steps b through h.
- j. Repeat steps b through i for each designated injection location.
- k. Repeat the generator performance verification and steps b through j for each designated waveform.
- l. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Table 22-1.1 Pin Injection Test Requirements

Waveform Set	Test Type	Test Levels	<u>Test</u> Waveform Nos. (Voc/Isc)
A (aperture coupling)	Pin	<u>Table 22-2</u>	3/3, 4/1
B (aperture and resistance coupling)	Pin	<u>Table 22-2</u>	3/3, 5A/5A

Table 22-1.2 Cable Bundle Test Requirements

Waveform Set	Test Type	Test Levels	Test Waveform Nos.
C (unshielded, aperture coupling)	Single Stroke	<u>Table 22-3</u>	2, 3
D (unshielded, aperture and resistance coupling)	Single Stroke	<u>Table 22-3</u>	2, 3, 4
E (shielded aperture coupling)	Single Stroke	<u>Table 22-3</u>	1, 3
F (shielded, aperture and resistance coupling)	Single Stroke	<u>Table 22-3</u>	3, 5A
G (unshielded, aperture coupling)	Single Stroke	<u>Table 22-3</u>	2, 3
	Multiple Stroke	<u>Table 22-4</u>	2, 3
H (unshielded, aperture and resistance coupling)	Single Stroke	<u>Table 22-3</u>	2, 3, 4
	Multiple Stroke	<u>Table 22-4</u>	2, 3, 4
J (shielded, aperture coupling)	Single Stroke	<u>Table 22-3</u>	1, 3
	Multiple Stroke	<u>Table 22-4</u>	1, 3
K (shielded, aperture and resistance coupling)	Single Stroke	<u>Table 22-3</u>	3, 5A
	Multiple Stroke	<u>Table 22-4</u>	3, 5A
L	Multiple Burst	<u>Table 22-5</u>	3
M	Multiple Burst	<u>Table 22-5</u>	6

Table 22-2 Generator Setting Levels for Pin Injection

Level	Waveforms		
	3/3	4/1	5A/5A
	Voc/Isc	Voc/Isc	Voc/Isc
1	100/4	50/10	50/50
2	250/10	125/25	125/125
3	600/24	300/60	300/300
4	1500/60	750/150	750/750
5	3200/128	1600/320	1600/1600

NOTES:

1. *Voc = Peak Open Circuit Voltage (Volts) available at the calibration point shown in Figure 22-10, Figure 22-11, or Figure 22-12.*
2. *Isc = Peak Short Circuit Current (Amps) available at the calibration point shown in Figure 22-10, Figure 22-11, or Figure 22-12.*
3. *Amplitude Tolerances +10%, -0%.*
4. *The ratio of Voc to Isc is the generator source impedance to be used during the calibration procedure.*
5. *Waveforms 3, 4 and 5A are identified in Figure 22-3, Figure 22-4 and Figure 22-5.*

Table 22-3 Test and Limit Levels for Cable Bundles Single Stroke Tests

Level	Waveforms				
	2/1	2/1	3/3	4/1 ^{Note 3}	4/5A
	V_L/I_T	V_T/I_L	V_T/I_L	V_T/I_L	V_L/I_T
1	50/100	50/100	100/20	50/100	50/150
2	125/250	125/250	250/50	125/250	125/400
3	300/600	300/600	600/120	300/600	300/1000
4	750/1500	750/1500	1500/300	750/1500	750/2000
5	1600/3200	1600/3200	3200/640	1600/3200	1600/5000

NOTES:

1. Amplitude tolerances are +20%, -0%.
2. Waveforms 1, 2, 3, 4 and 5A are identified in Figure 22-1, Figure 22-2, Figure 22-3, Figure 22-4 and Figure 22-5, respectively.
3. When testing with voltage waveform 4, the current waveform will be dependant on cable impedance.

Table 22-4 Test and Limit Levels for Cable Bundle Multiple Stroke Tests

Level		Waveforms				
		2/1	2/1	3/3	4/1 ^{Note 4}	4/5A
		V _L /I _T	V _T /I _L	V _T /I _L	V _T /I _L	V _L /I _T
1	First Stroke	50/50	50/50	100/20	25/50	20/60
	Subsequent Stroke	25/25	25/25	50/10	12.5/25	10/30
2	First Stroke	125/125	125/125	250/50	62.5/125	50/160
	Subsequent Stroke	62.5/62.5	62.5/62.5	125/25	31.25/62.5	25/80
3	First Stroke	300/300	300/300	600/120	150/300	120/400
	Subsequent Stroke	150/150	150/150	300/60	75/150	60/200
4	First Stroke	750/750	750/750	1500/300	375/750	300/800
	Subsequent Stroke	375/375	375/375	750/150	187.5/375	150/400
5	First Stroke	1600/1600	1600/1600	3200/640	800/1600	640/2000
	Subsequent Stroke	800/800	800/800	1600/320	400/800	320/1000

NOTES:

1. Amplitude tolerance for the first stroke is +20%, -0%. Amplitude tolerance for the subsequent stroke is +50%, -0%.
2. Waveforms 1, 2, 3, 4 and 5A are identified in Figure 22-1, Figure 22-2, Figure 22-3, Figure 22-4 and Figure 22-5, respectively.
3. Multiple Stroke is identified in Figure 22-7.
4. When testing with voltage waveform 4, the current waveform will be dependant on cable impedance.

Table 22-5 Test Levels for Cable Bundle Multiple Burst Tests

Level	Waveform	Waveform
	3	6
	V_T/I_L	V_L/I_T
1	60/1	100/5
2	150/2.5	250/12.5
3	360/6	600/30
4	900/15	1500/75
5	1920/32	3200/160

NOTES:

1. Amplitude tolerances are +20%, -0%.
2. Waveform 3 is identified in Figure 22-3, waveform 6 is identified in Figure 22-6.
3. Multiple Burst is identified in Figure 22-8.
4. Under each waveform, V_T represents the test voltage level in Volts, and I_T represents the test current level in Amperes. V_L (Volts) and I_L (Amperes) represent limits intended to prevent over-stressing the EUT beyond requirements.
5. Waveform 6 is applicable, in lieu of waveform 3, when EUT installations meet criteria defined in Section 22.5.2.i (3).

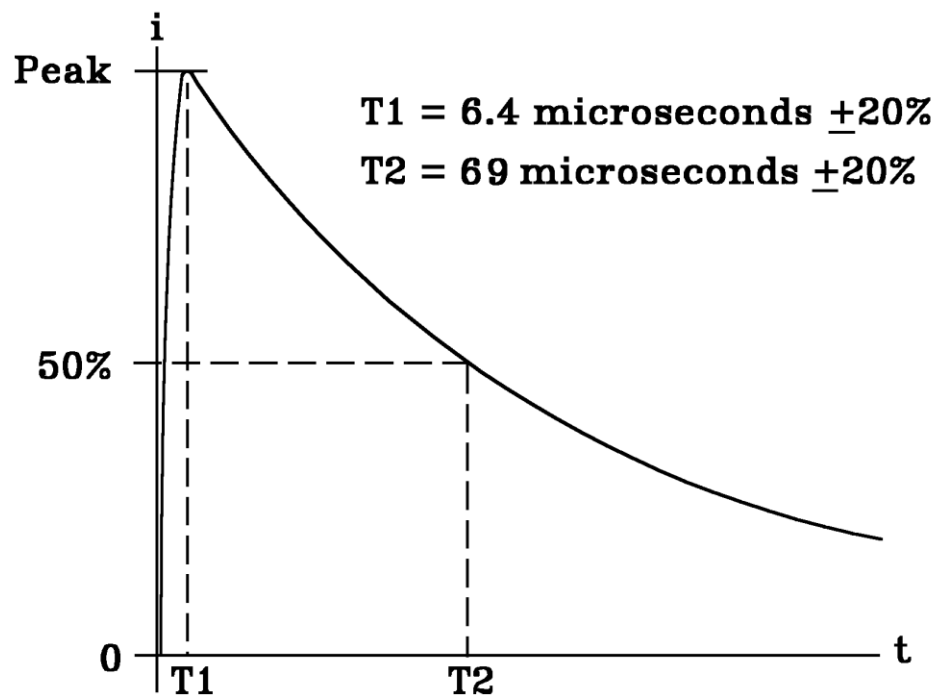


Figure 22-1 Current Waveform 1

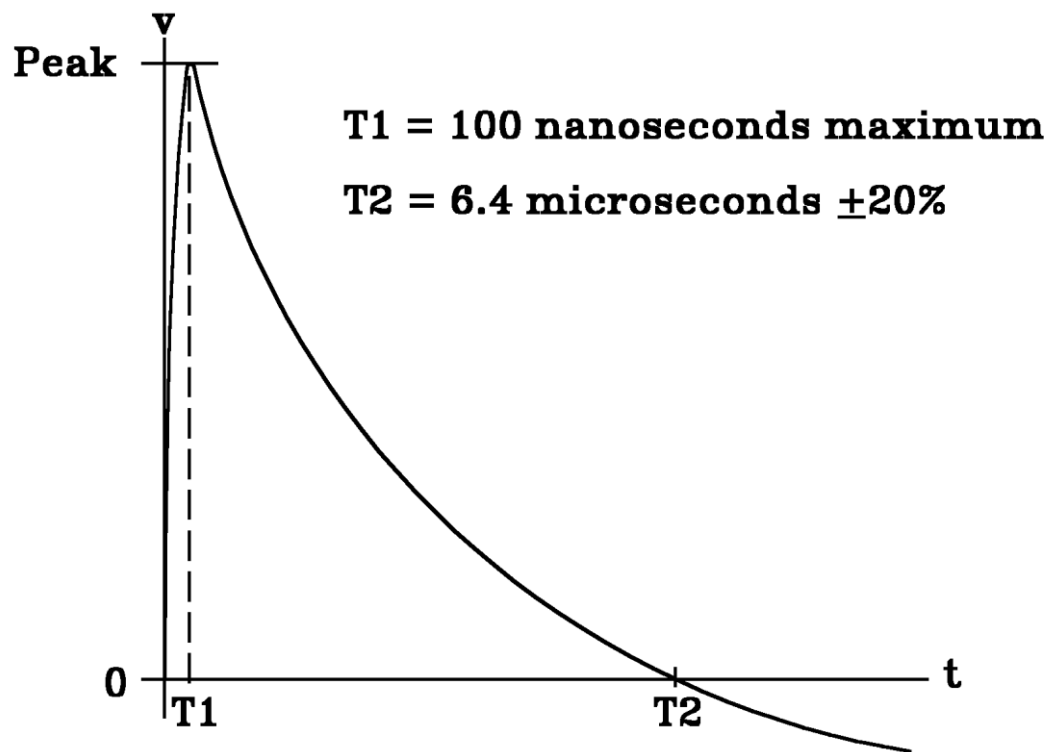
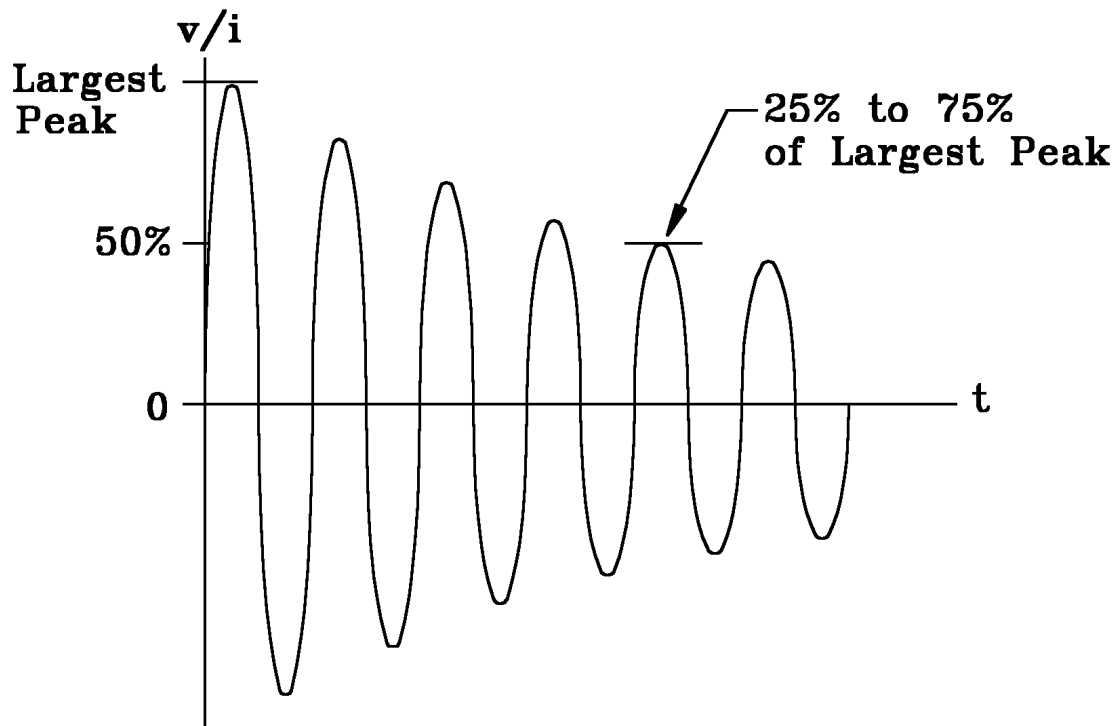


Figure 22-2 Voltage Waveform 2



NOTES:

1. Voltage and current are not required to be in phase.
2. The waveshape may have either a damped sine or cosine waveshape.

Figure 22-3 Voltage/Current Waveform 3

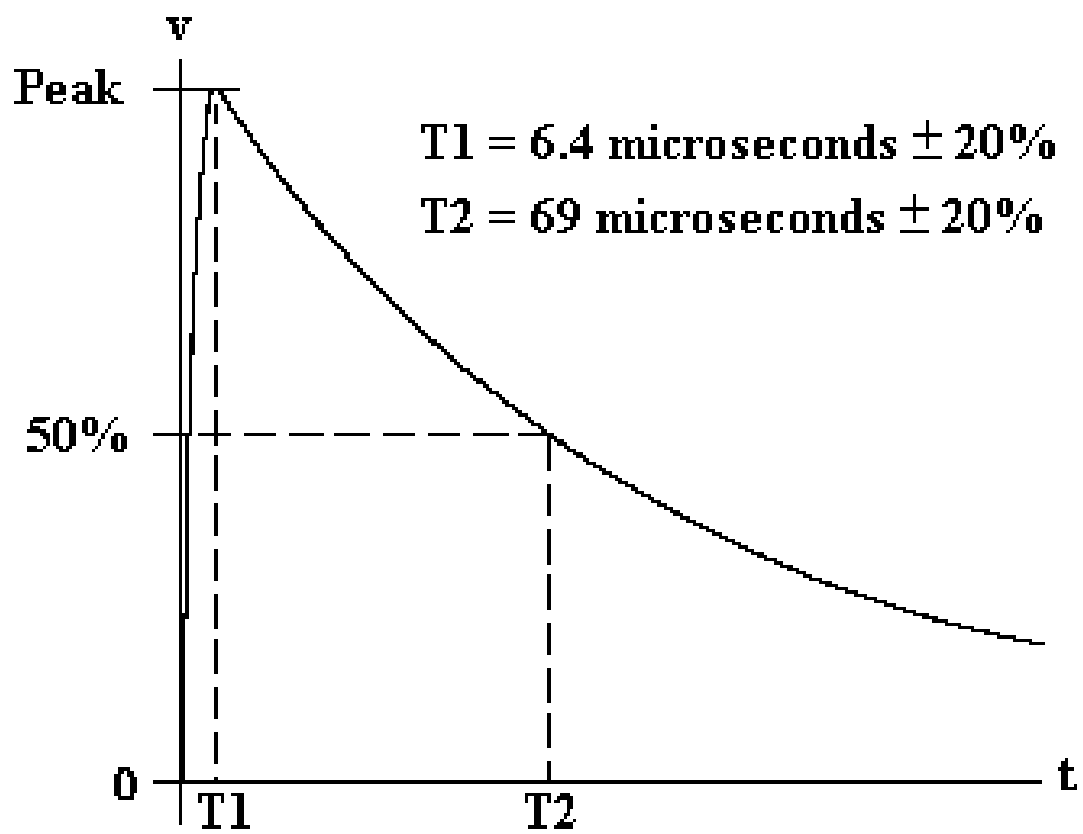


Figure 22-4 Voltage Waveform 4

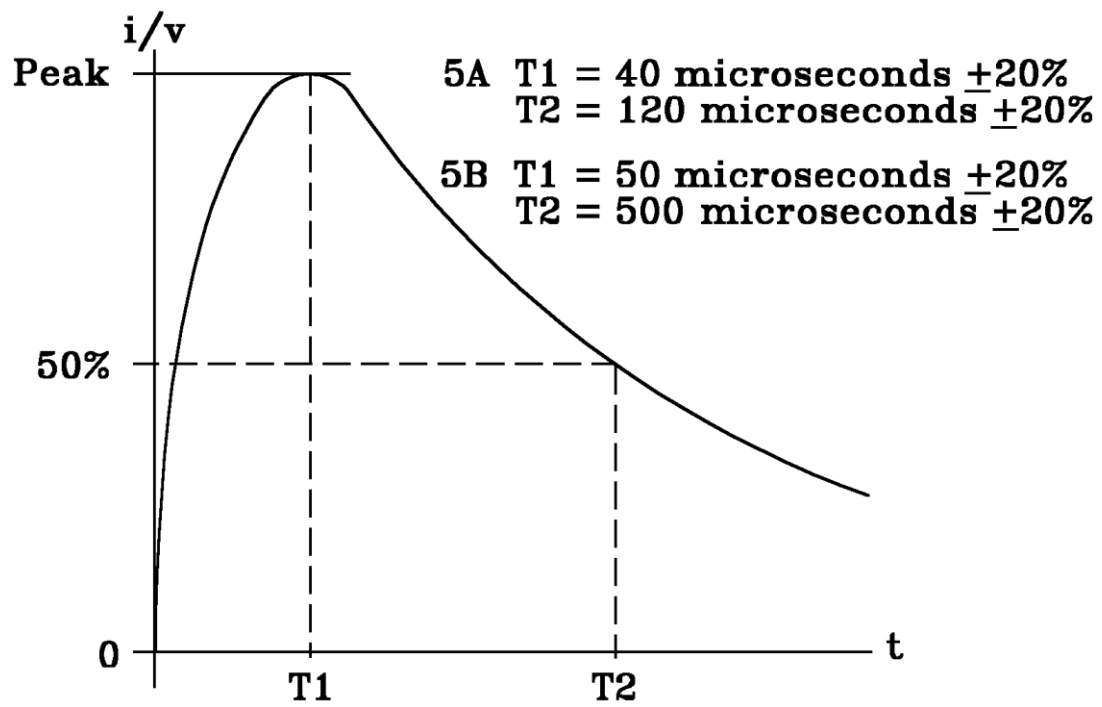


Figure 22-5 Current/Voltage Waveform 5

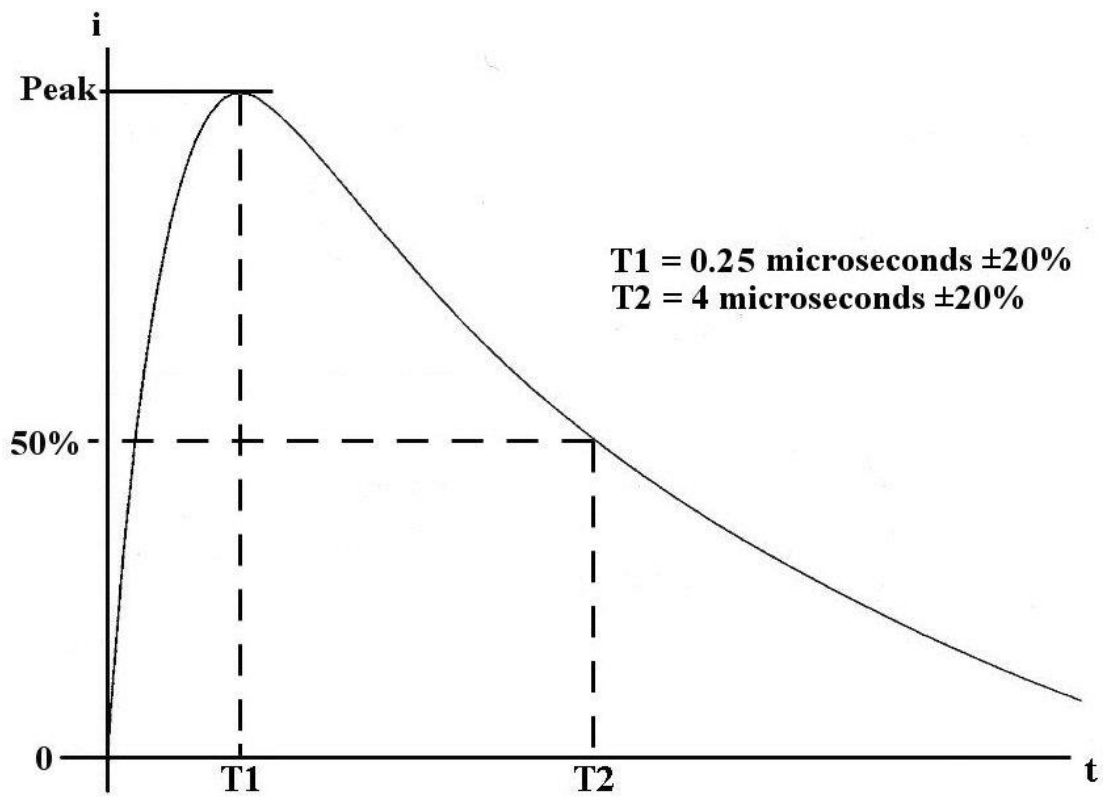


Figure 22-6 Current Waveform 6

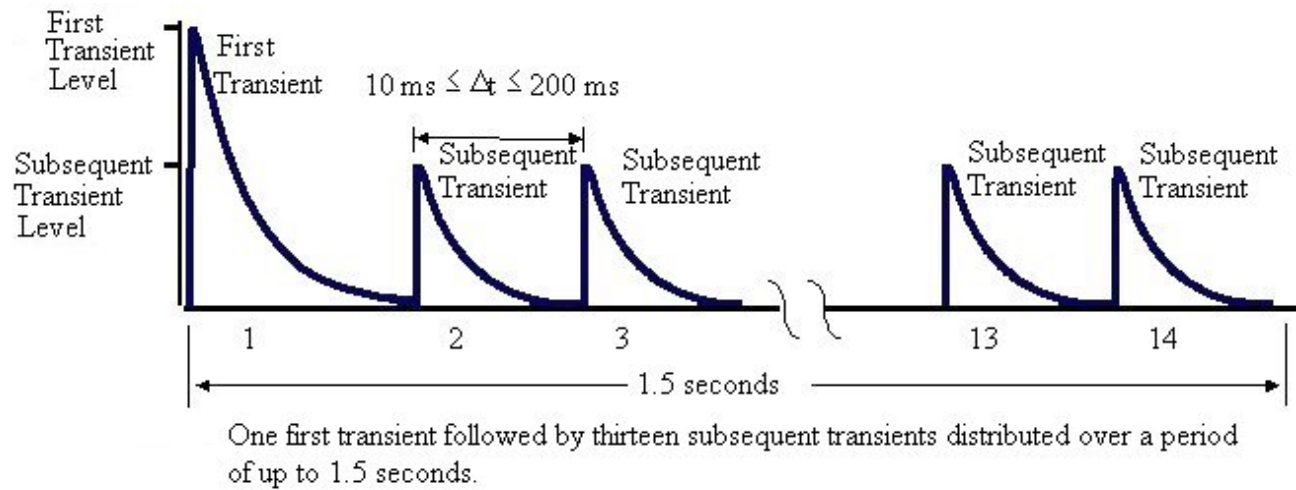


Figure 22-7 Multiple Stroke Application

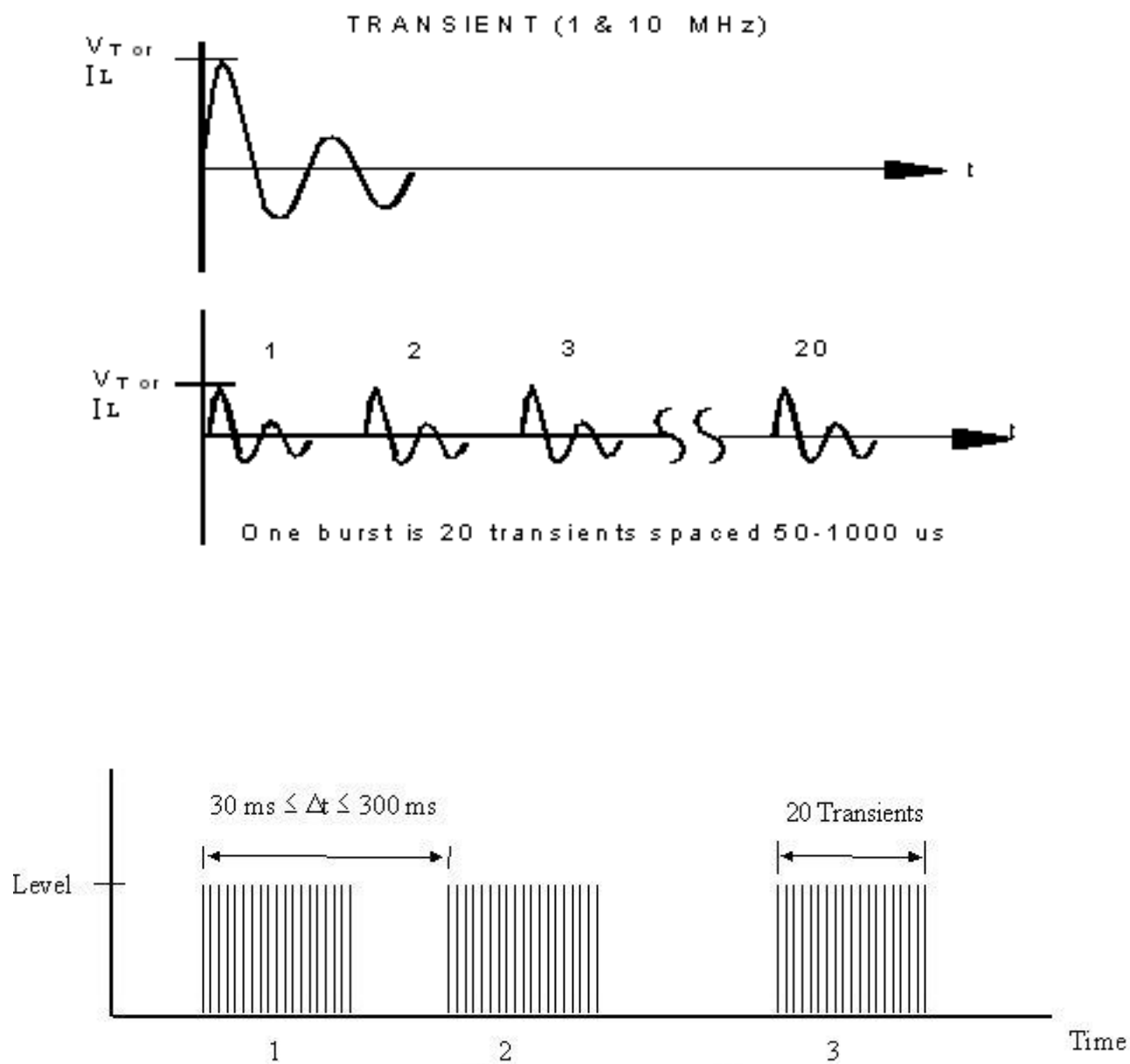


Figure 22-8 Multiple Burst Application

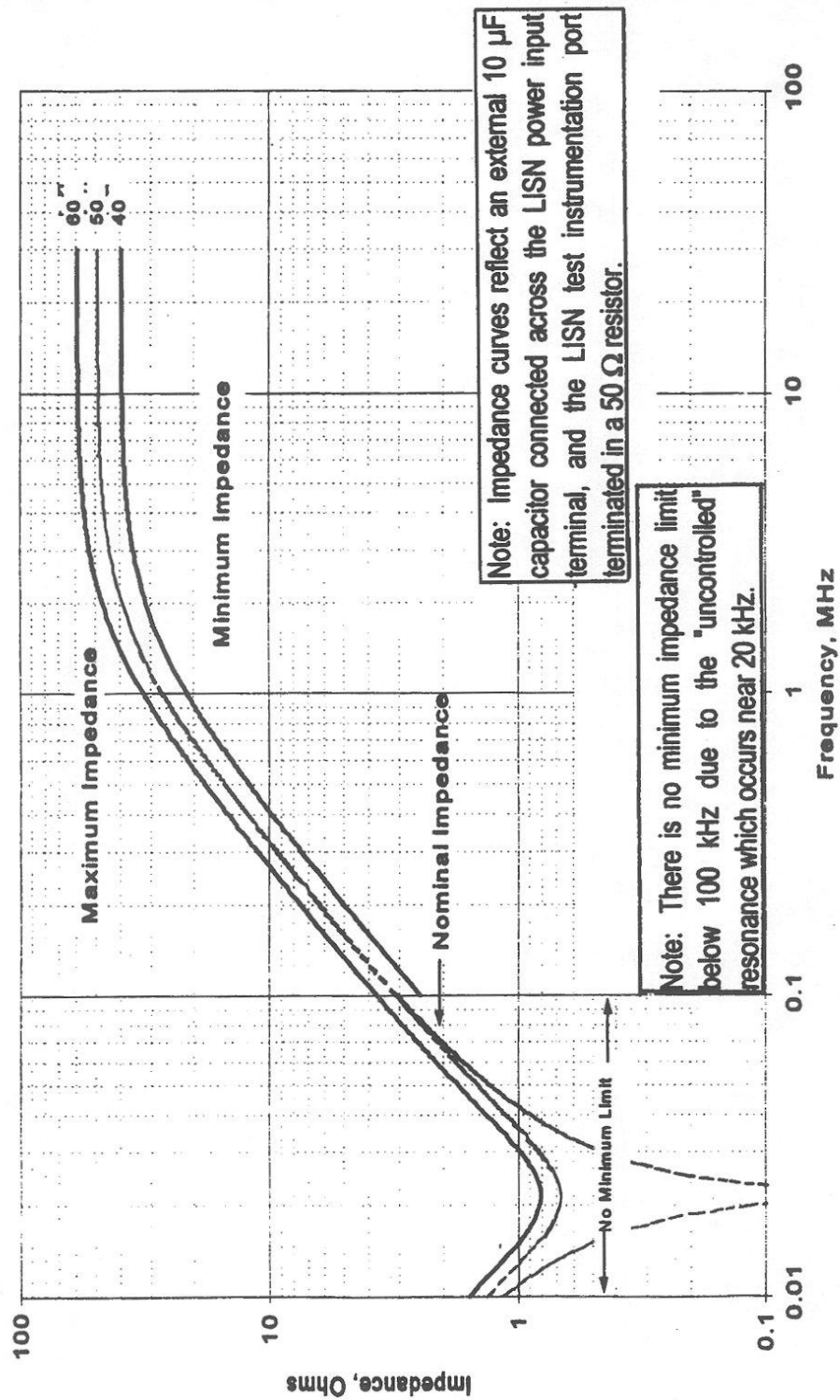
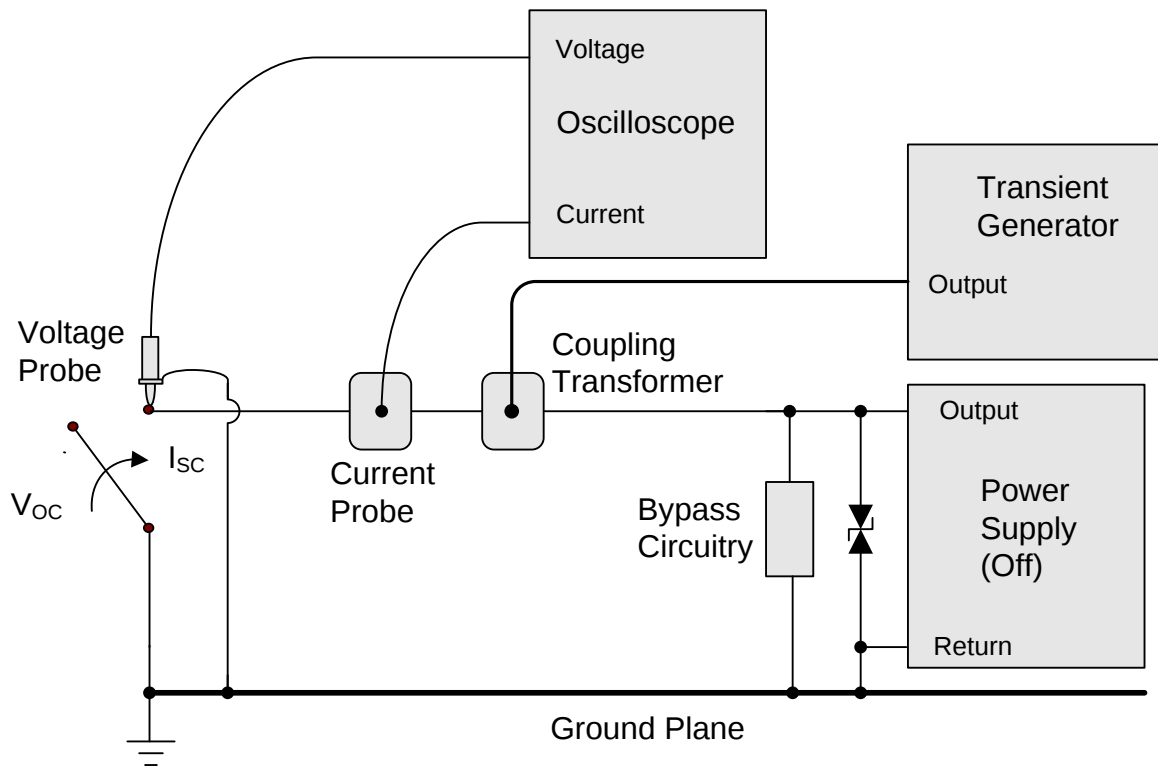


Figure 22-9 LISN Input Impedance Characteristic

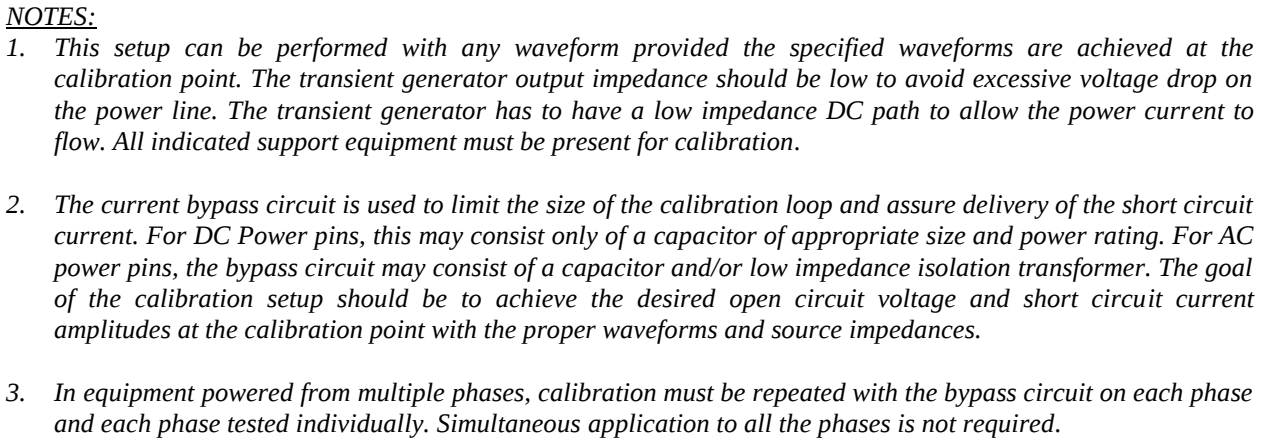
1. Tests of active ac power circuits may require transformer coupling of the applied transients to the power lines and transients should be synchronized to the peak of the ac waveform.
2. A power blocking device may be used to isolate voltages at the pins of the EUT from the low generator impedance and must be present during calibration since they may adversely affect the waveform calibration. Typical power blocking devices are bipolar suppression devices for Waveforms 4 and 5 or a series capacitor for Waveform 3. The bipolar suppression device is selected with a voltage rating close to the expected EUT operating voltage but may have a nominal value to allow testing with one calibrated setup. A voltage rating that represents a significant percentage of the applied transient will affect waveform calibration. The capacitor is selected to achieve the calibration current; too large a value may produce unwanted resonance during test.
3. The Power Blocking Device is not necessary for tests on un-powered equipment.

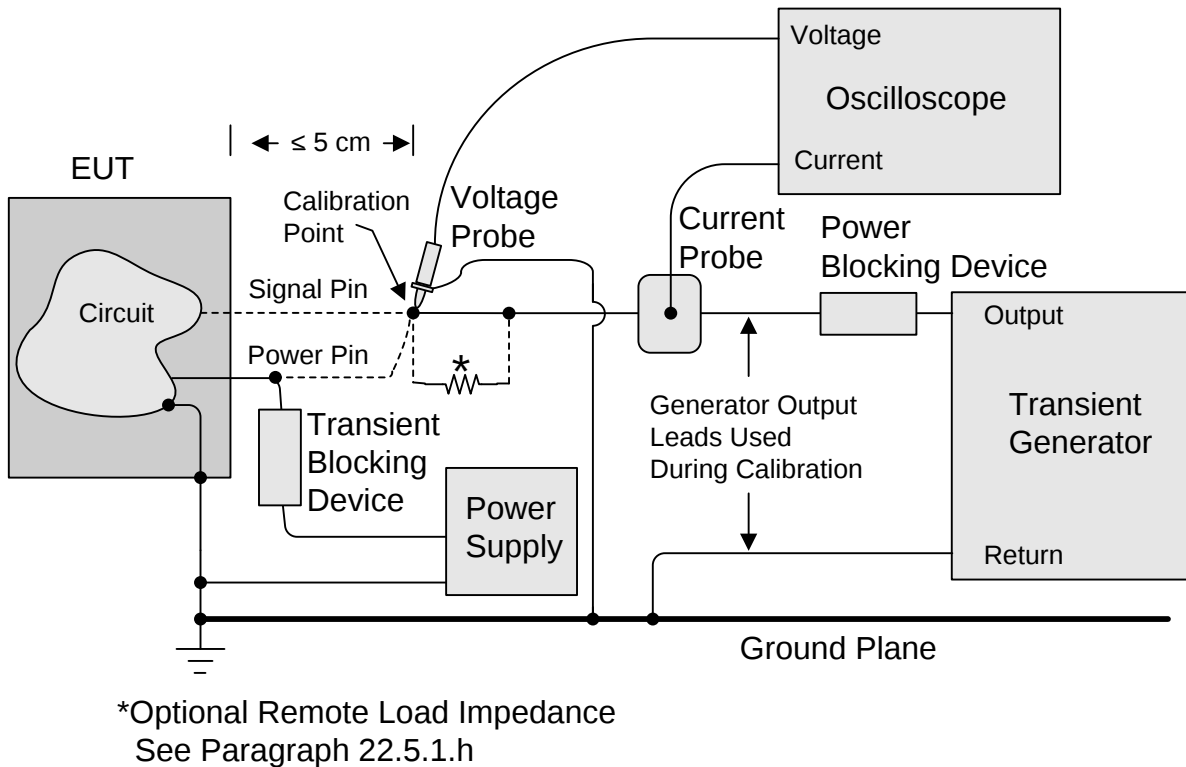
Figure 22-10 Pin Injection Calibration Setup, Signal Pins & Power Pins – Direct Injection Method

**NOTES:**

1. This setup can be performed with any waveform provided the coupling transformer can adequately support the open circuit voltage waveform and related short circuit current. All indicated support equipment must be present for calibration. Specified waveforms must be achieved at the calibration point. The bypass circuitry and power supply (turned off) must be present for calibration.
2. The current bypass circuit is used to limit the size of the calibration loop and assure delivery of the short circuit current. For DC Power pins, this may consist only of a capacitor of appropriate size and power rating. For AC power pins, the bypass circuit may consist of a capacitor and/or low impedance isolation transformer. The goal of the calibration setup should be to achieve the desired open circuit voltage and short circuit current amplitudes at the calibration point with the proper waveforms and source impedances.
3. In equipment powered from multiple phases, calibration must be repeated with the bypass circuit on each phase and each phase tested individually. Simultaneous application to all the phases is not required.

Figure 22-11 Pin Injection Calibration Setup, Power Pins – Cable Induction Method

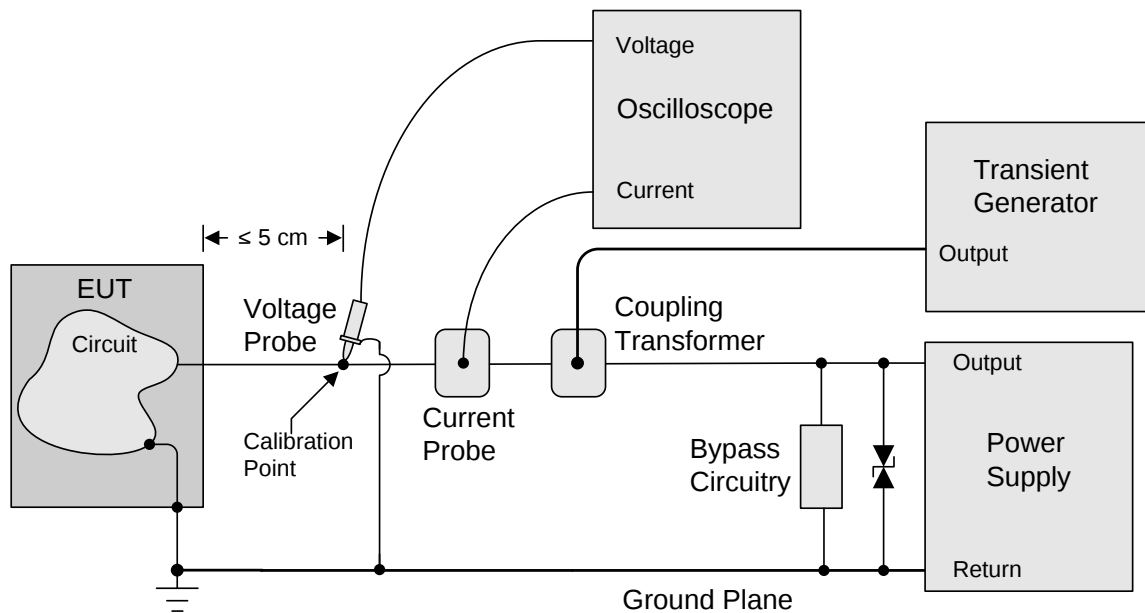




NOTES:

1. The notes from the calibration setup of *Figure 22-10* apply.
2. Test setup and procedures are to be such that the required lightning transients appear differentially between the aircraft power and return/neutral lines. If power and return/neutral originate from a remote load, in the same cable bundle with signals, then the test setup should use an isolated power return to ensure the proper common-mode evaluation.
3. The power supply is not necessary for tests on un-powered equipment.
4. Test procedures assume lightning transients appear common-mode between all pins and case. If the expected installation utilizes local power and/or signal returns tied either internally or externally to case or aircraft structure, tests shall be performed with the return(s) tied to the case.
5. Return wire lengths shall be kept as short as possible.

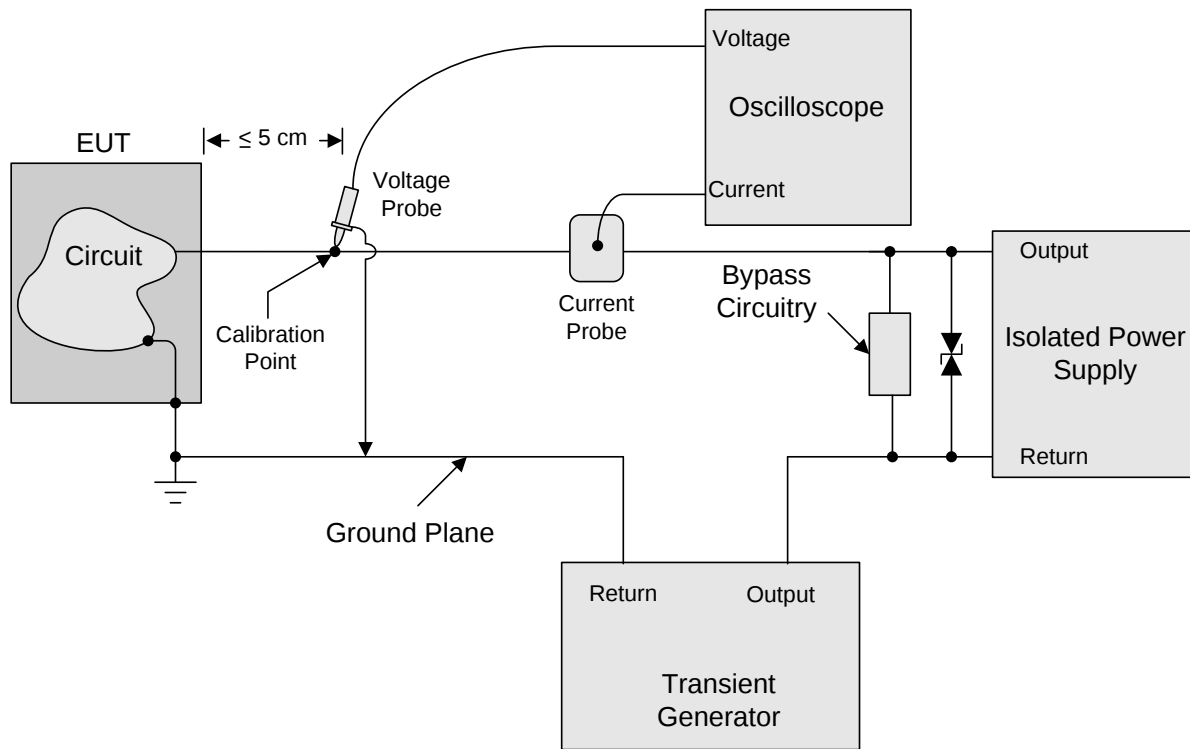
Figure 22-13 Pin Injection Test Setup, Signal Pins & Power Pins – Direct Injection Method



NOTES:

1. The notes from the calibration setup of Figure 22-11 apply.
2. Test setup and procedures are to be such that the required lightning transients appear differentially between the aircraft power and return/neutral lines. If power and return/neutral originate from a remote Load, in the same cable bundle with signals, then the test setup should use an isolated power return to ensure the proper common-mode evaluation.
3. Injection should also be performed on the power return/neutral unless it is tied directly to case at the connector.
4. Return wire lengths shall be kept as short as possible

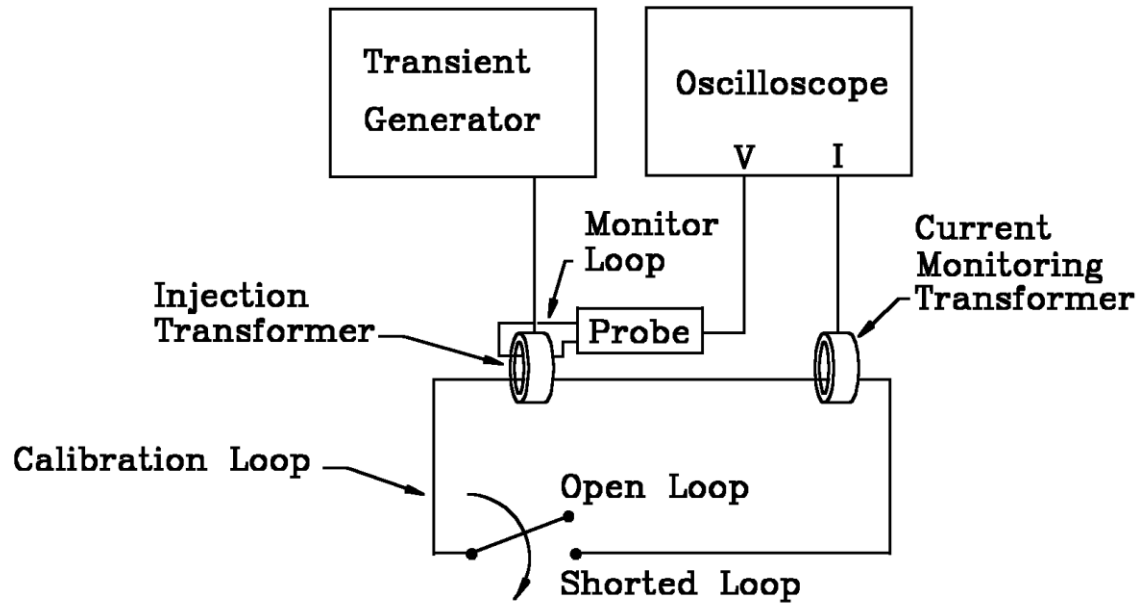
Figure 22-14 Pin Injection Test Setup, Power Pins - Cable Induction Method



NOTES:

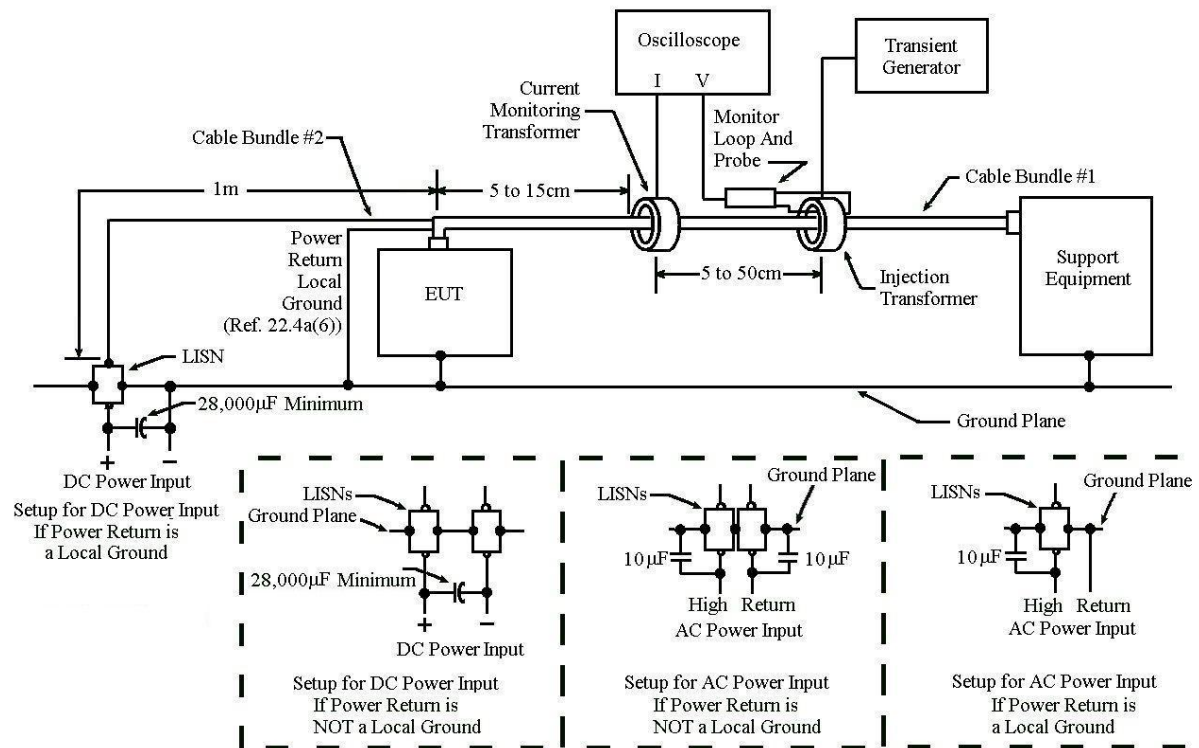
1. The notes from the calibration setup of [Figure 22-12](#) apply.
2. Test setup and procedures are to be such that the required lightning transients appear differentially between the aircraft power and return/neutral lines. If power and return/neutral originate from a remote load, in the same cable bundle with signals, then the test setup should use an isolated power return to ensure the proper common-mode evaluation.
3. Injection should also be performed on the power return/neutral unless it is tied directly to case at the connector.
4. EUT return wire lengths shall be kept as short as possible

Figure 22-15 Pin Injection Test Setup, Power Pins - Ground Injection Method



NOTE: A series current-monitoring resistor may be used instead of the current-monitoring transformer.

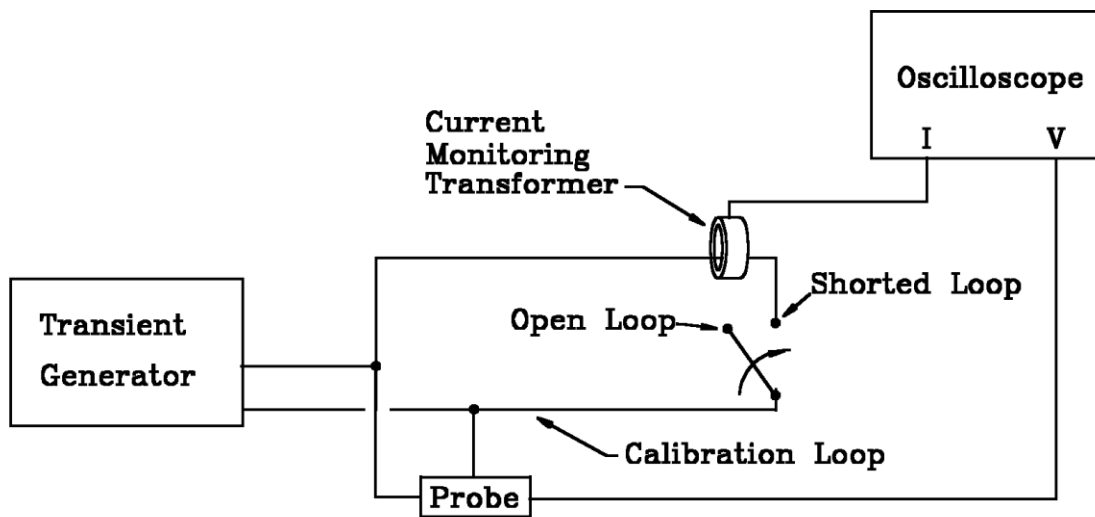
Figure 22-16 Typical Generator Performance Verification Setup for Cable Induction Tests



NOTES:

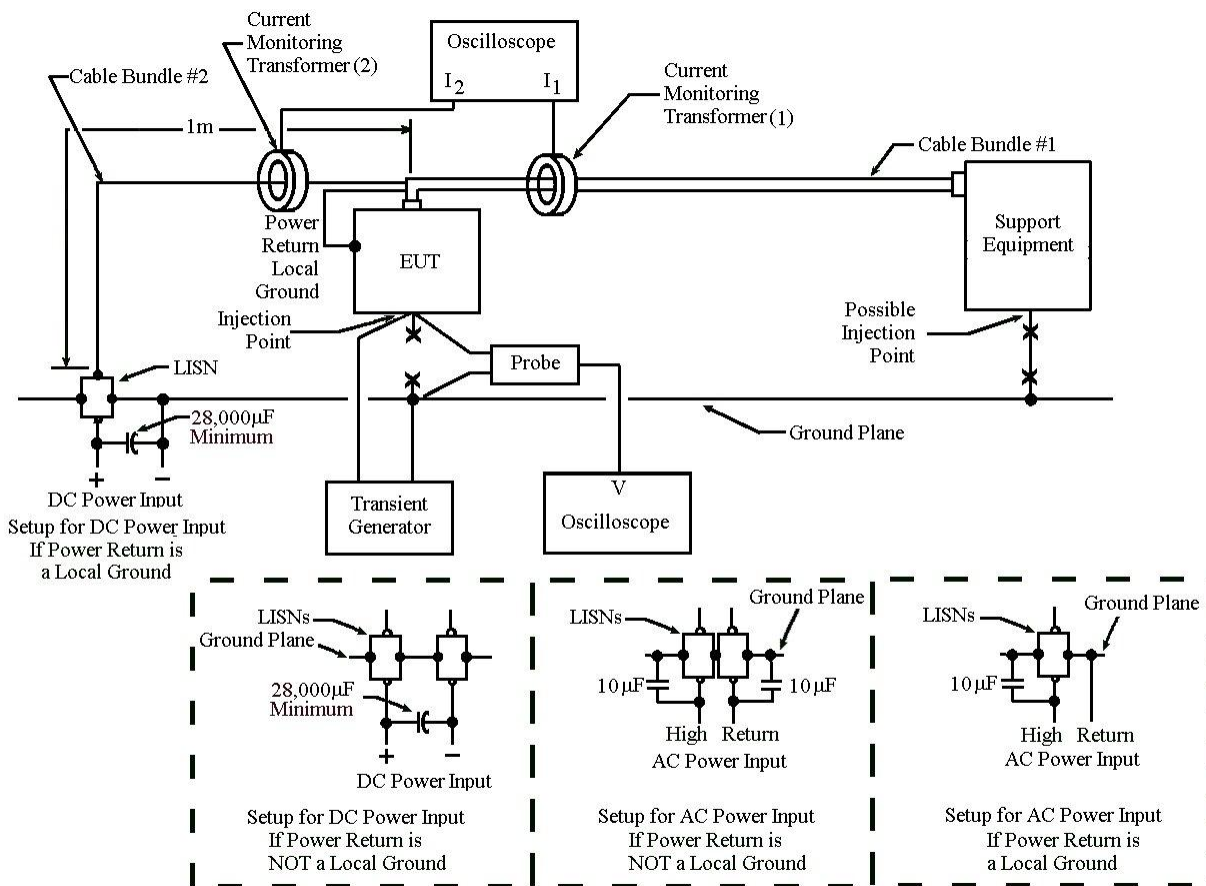
1. Capacitor(s) shall be applied on power inputs to provide a low impedance to ground, as shown.
2. A series current-monitoring resistor may be used instead of the current-monitoring transformer.

Figure 22-17 Typical Cable Induction Test Setup



NOTE: A series current-monitoring resistor may be used instead of the current-monitoring transformer.

Figure 22-18 Typical Generator Performance Verification Setup for Ground Injection Tests



NOTES:

1. Capacitor(s) shall be applied on power inputs to provide a low impedance to ground, as shown
2. The transient generator output impedance should be low to avoid excessive voltage drop on the power line. The transient generator has to have a low impedance path to allow the power current to flow.
3. A series current-monitoring resistor may be used instead of the current-monitoring transformer.

Figure 22-19 Typical Ground Injection Test Set-up

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RTCA/DO-160G,

**Environmental Conditions and Test
Procedures for Airborne Equipment**

User's Guide Appendix 22

Lightning Induced Transient Susceptibility

**Based on
DO-160G Section 22**

Date of Issue:
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Supersedes: RTCA/DO-160F
Prepared by: SC-135
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User's Guide, Appendix 22

Section 22 defines the environment, test procedures and requirements. In order to properly interpret the procedures and requirements outlined in Section 22, a User's Guide is provided in Appendix 22.

The User's Guide includes rationale, guidance and background information for the environment, test procedure and requirements, guidance in applying the requirements, and lessons learned from aircraft and laboratory experience. This information should help user's understand the intent behind the requirements, should aid in tailoring requirements as necessary for particular applications and should help user's develop detailed test procedures based on the general test procedures in Section 22.

The User's Guide follows a parallel format to the main body of Section 22 for easy cross reference. Paragraph numbers corresponding to each paragraph in Section 22 are included the User's Guide. Where there is no additional information provided in the User's Guide, the paragraph header is provided but the following paragraph is left blank.

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22.0 Lightning Induced Transient Susceptibility

22.1 Purpose of Tests

This section of DO-160 is intended to provide test procedures and test levels that can be used to test equipment for indirect effects of lightning. It is the responsibility of the installer to make sure the test results satisfy the certification requirements of the proposed installation. This user's guide does not contain requirements; it is intended to provide background information and considerations that improve the likelihood of successful test results.

22.2 Definitions

Cable Bundles

Generally an interconnect bundle to be tested is associated with one connector. Grouping multiple connector bundles together during the test may not induce the appropriate current in the individual connector bundle.

Local Ground

For the purposes of DO-160 Section 20, 21 and 22 testing, a local ground is defined as a ground wire less than 1 meter in length. In actual installations there may be many exceptions to this rule. EUT's may be grounded locally but the ground wire may exceed 1 meter. As the length of the ground wires increases, the likelihood of lightning energy coupling onto that wire increases. If it is anticipated that the ground wires in the installed configuration will exceed 1 meter, testing of that wire should be considered. However as specified in the requirements, if the wire is not known to be run with the normal interconnect bundle for its entire length, it should not be included along with the bundle during test and should be tested separately.

Low Impedance Shielded Cable Bundle

A low impedance shielded cable bundle may have any or all of the following characteristics. The bundle is physically short, routed close to the ground plane, contains well terminated shields (such as with 360 degree shield termination or very short pigtail termination wires), and has well bonded connectors and equipment mating surfaces. This definition is only pertinent to the application of Waveform 6 as the multiple burst cable bundle test waveform.

22.3 Categories

There is no requirement that pin injection and cable bundle test levels are identical. There is also no requirement that the single/multiple stroke test level and multiple burst test level be identical.

Separate designations for pin, single/multiple stroke and multiple burst allow for the selection of the maximum level desired in each category, which may allow the EUT to be installed in more applications.

The use of category Z does not mean that the EUT has not met the requirements of a particular category or that the test was unacceptable. Category Z means that the installer should look at the Environmental Qualification Form and/or Environmental Qualification Report for additional test data. The use of Category Z may be acceptable to the installer after reviewing the actual test data.

22.3.1 Waveform Set Designators (First and Third and Fifth Characters)**22.3.2 Test Level Designators (Second, Fourth and Sixth Characters)****22.4 General Test Requirements****a. Equipment Under Test**

- (1) Ground Plane
- (2) Shock and Vibration Isolators
- (3) Electrical Bonding

Bonding the EUT to a copper or aluminum table may be considered an “ideal” bonding arrangement. In one installation the EUT may be installed in a rack and in another, installed in a panel.

- (4) External Ground Terminal
- (5) Interconnecting Wiring/Cable Bundles
- (6) Power Leads
- (7) Interface Loads and Support Equipment
- (8) Dummy Antennas or Loads

b. Test equipment

- (1) Bonding
- (2) Line Impedance Stabilization Network

The purpose of the LISN is to standardize the impedance of the power source that provides input power for the EUT(s). LISN(s) need to be used whenever the power source impedance could affect test results, such lightning testing of the power leads. This control is needed because the power supply source impedance can vary from one facility to another for a variety of reasons, e.g. different power supplies, power line lengths, EMI filtering, wire size, etc.... This stabilization ensures consistent results between test facilities. The LISN normally used for DO-160 EMI and lightning testing is a 5 μ H LISN which simulates the power line impedance of small to moderate sized aircraft; however this is not specified as a requirement. The impedance chart (Figure 22-9) is based on the impedance of a 5 μ H LISN.

The use of the 5 μ H LISN was driven by RF susceptibility, RF emissions and lightning tests in which procedures required testing below 150 KHz. Certain problems were observed with the 5 μ H LISN, such as a resonance near 70 kHz. This was resolved by adding the 10 μ F cap which moved the resonance down to approximately 20 kHz. Additional capacitance would further lower the resonance but would start to adversely affect 400 Hz power sources. Figure 22-9 illustrates the LISN impedance, with the external 10 μ F included. The impedance tolerance has been widened above 150 MHz due to measurement uncertainty. It should be noted that since the 10 μ F capacitor is necessary for meeting the impedance curve of Figure 22-9, this capacitor must also be included in the test setups. Additionally, Figure 22-17 shows additional capacitance across the LISN for DC testing. The purpose of this capacitance is DC power supply protection. This additional protection is generally not required for AC power sources and would increase the 400 Hz input current shunted through the capacitor to ground.

(3) Measurement Probes and Injection Transformers

Oscilloscopes

Some factors that should be considered when selecting an oscilloscope to measure lightning waveforms are:

- Oscilloscope Bandwidth
- Oscilloscope Sample Rate
- Oscilloscope Timebase and Memory Length

Oscilloscope Bandwidth

Oscilloscope Bandwidth is specified at the -3 dB point on the frequency-response curve. Another way of expressing -3 dB is -29%. Therefore at the bandwidth frequency, the amplitude measurement accuracy is -29%. The upper frequency of the Bandwidth must be high enough to provide sufficient accuracy.

Oscilloscope manufacturers give the following guidance:

Use a BW in MHz $\geq 0.45/tr$, where tr is the 10% to 90% rise time of the waveform in μ S. The amplitude measurement accuracy would still be -10% with this bandwidth. A BW $\geq 1/tr$ improves the amplitude measurement accuracy to -2%.

For sinusoidal waveforms, $tr = t_{period}/5$.

Examples:

For WF3 10 MHz sinusoidal measurements, $tr = 100 \text{ ns}/5 = 20 \text{ ns}$:

Use a BW $\geq 1/20 \text{ ns} \geq 50 \text{ MHz}$.

For WF2 ~80 ns rise time:

Use a BW $\geq 1/80 \text{ ns} \geq 12.5 \text{ MHz}$

Oscilloscope Sample Rate

Digital Oscilloscope Sample Rate is the number of data points recorded per second. Single-shot sampling is required to capture single triggered lightning waveforms. The sample rate must be high enough to provide sufficient accuracy.

Oscilloscope manufacturers give the following guidance:

To prevent aliasing, the Nyquist Theorem says you must have at least 2 samples per period in order to reconstruct the basic frequency information.

Most manufacturers recommend a minimum sample rate of two times $1/tr$. This is also expressed as 10 samples per period.

Examples:

For WF3 10 MHz sinusoidal measurements, $tr = 100 \text{ ns}/5 = 20 \text{ ns}$:

Use a Sample Rate $\geq 2 \times 1/20 \text{ ns} \geq 100 \text{ MS/s}$.

For WF2 ~80 ns rise time:

Use a Sample Rate $\geq 2 \times 1/80 \text{ ns} \geq 25 \text{ MS/s}$.

Oscilloscope Timebase and Memory Length

Timebase is the time per oscilloscope division. Memory length is the amount of sample memory per oscilloscope channel. The timebase should be adjusted to the minimum needed to display all the applicable waveform parameters of T1, T2 and damping. The memory length should be large enough to maintain the calculated sample rate.

Current and Voltage Probes

Some factors that should be considered when selecting a current and voltage probe to measure lightning waveforms:

- Probe Bandwidth/Frequency Response
- Probe Maximum Peak Capacity (single pulse waveforms)
- Probe Maximum RMS Capacity (power lead measurements)
- Current Probe Saturation Limits
- Current Probe Transfer Impedance (voltage to current ratio)
- Current Probe Measurement Impedance
- Current Probe construction (fixed window vs. clamp-on)
- The Current Probe must be electro-statically shielded

Probe Bandwidth/Frequency Response

Ideally, the probe should have a flat (or as flat as possible) response, across the entire frequency range that is required. Waveforms have frequency components of several MHz, and/or frequency components to accurately measure the calibration and test waveforms. For instance, in the low kHz, a probe with a broadband, yet flat frequency response is necessary for accurate measurements in the frequencies of interest.

Probe Maximum Peak Capacity

For Single Pulse waveforms, it is recommended that the peak capacity of the probe should be at least two times the expected peak to be measured, to ensure that the probe will not saturate and distort the waveform.

Probe Maximum RMS Capacity

When tests are performed on a power lead that is carrying continuous AC or DC power, the maximum RMS capacity of the probe must be considered. It is recommended that the RMS Current Capacity of the probe should be at least two times the expected RMS current level to be measured, to ensure that the probe will not saturate and distort the waveform.

Current Probe Saturation Limits

Current probes have saturation limits that should not be exceeded to assure correct current measurements.

For Single Pulses, be sure that the current probe is rated for the Current x Time product of the pulse.

For Example: WF5B Level 5 is $5000\text{A} \times 500\mu\text{s} = 2.5 \text{ Amp-Sec}$.

For Continuous Waveforms, be sure that the current probe is rated for the Current / Frequency quotient of the pulse.

For Example: WF3 1MHz Level 5 is $640\text{A}/1\text{MHz} = 0.001 \text{ Amp/Hz}$.

If the current probe manufacturer does not specify saturation limits, contact them with your waveforms for guidance on selecting the proper current probe.

Current Probe Transfer Impedance (voltage to current ratio)

Commercially available current probes have a transfer impedance that varies widely, typically between -20 dB (1:10) to 60 dB (1000:1). Transfer Impedance is often referred to as the oscilloscope's probe factor or attenuation factor and may be applied as either a dB factor or a current to voltage ratio. For example, 26 dB or 20:1 could be applied for a current probe that develops 1 Volt across its connector for every 20 Amps of transient current. As described above, the transfer impedance should be a flat 26 dB across the entire range of the waveform's frequency components.

Selecting a current probe with a transfer impedance that is either too high or too low can result in over-driving or under-driving the oscilloscope. Since the test category current levels vary widely, different probes or probe/attenuator configurations may be required to protect the oscilloscope yet still display a clean and usable waveform.

Current Probe Construction

Care should be taken when using clamp-on current probes to make sure that contacts between the halves of the clamp-on current probe are clean and properly aligned to provide consistent contact between the probe halves.

Measurement Impedance

Commercially available current probes are typically designed to be used with a digital oscilloscope employing a measurement impedance of either 50 Ω or 1 M Ω . For accurate current measurements, always set the oscilloscope to the measurement impedance for which the current probe is designed.

Injection Transformer

As a general rule, any injection transformer (also known as a clamp, coupling transformer or injection probe) that will produce an acceptable voltage and current waveform during the generator verification procedure or during the actual test on the cable, is an acceptable injection transformer for the particular test waveform.

Some factors that should be considered when selecting an injection transformer for Cable Bundle and/or Pin Injection tests:

- Bandwidth / Frequency Response
- Saturation
- Injection Transformer Construction

Bandwidth / Frequency Response

Because injection transformers must be designed to efficiently transfer a transient waveform to the cable under test, without internal arcing or saturation that causes distortion of the waveform, and they must produce the proper rise time and duration of the test waveforms, there are always tradeoffs between performance and other factors, such as convenience or versatility. This being the case, the bandwidth of an injection transformer is usually very limited, with a particular injection transformer being "tuned" to some degree for a particular waveform.

Proper design of an injection transformer, especially for tests at very high voltage and/or current levels, is sometimes considered to be "more art than science" and therefore has resulted in a variety of different designs that all generally have one thing in common – a particular transformer will work very well for a particular waveform, but will not always work well for other waveforms. Unique injection transformers or injection transformer configurations (e.g. different turns, air gaps, etc.) are usually required for each test waveform.

Note that the same injection transformer and configuration must be used for performance verification and testing.

Saturation

A typical limiting factor for an injection transformer is the saturation point. Care must be taken when selecting an injection transformer, so that the test waveform will be efficiently coupled to the cable or lead under test, without distortion of the test waveform due to transformer saturation. Proper construction material that is matched to the frequency components of the test waveform is required, especially at the highest test levels. Iron cores may perform better for the longer duration waveforms, and ferrite cores may be better for waveforms with faster rise times and shorter durations. Many different variations on these general themes are available from different vendors, and have also been “custom-built” by different testing laboratories.

When tests are performed on a power lead or bundle that is carrying AC or DC power current, the effect of the power current on the saturation point of the transformer must be considered. The power currents could cause saturation of the injection transformer, and distortion of the test waveform, even though the waveform verification procedure gave a waveform that was acceptable.

Injection Transformer Construction

Injection Transformers are not required to have electrostatic shielding.

A fixed-window injection transformer will typically provide better performance than a clamp-on injection transformer, but due to the nature of a typical Cable Induction test setup, a fixed window style injection transformer is usually difficult to work with. Again, there is a trade off of convenience for performance.

The other construction feature to note is that longer duration waveforms usually require an injection transformer with more ferrous material to avoid saturation or distortion. To handle a high level Waveform 5A or 5B test, an injection transformer constructed with about 500 pounds of iron is not unusual. On the other hand, an injection transformer used for Waveform 3 at 10 MHz may be a general purpose RF injection transformer that could also be used for RF Conducted Susceptibility testing, and is constructed with a few small ferrite cores weighing only a pound or two.

Commercially available injection transformers may have an input to output turns ratio that may vary from 5:1 to 1:4, with multiple steps in between. The various turns ratios allow for flexibility in matching the generator to the cable under test. Caution: Changing the turns ratio on an injection transformer may cause it to saturate sooner. Other injection transformers have a fixed turns ratio, typically 1:1 or 2:1. In general, using a turns ratio that will step up the current can be useful for a test on a shielded bundle using a waveform with a high current test level. Conversely, if the test is performed on an unshielded bundle, using a voltage waveform, with a high voltage test level, a turns ratio that steps up the voltage may be helpful.

- c. Data Required In Test Report
 - (1) Cable Configuration(s)
 - (2) Test Setups
 - (3) EUT Operating Mode(s)
 - (4) Load(s)
 - (5) Test Waveforms and Levels
 - (6) Applied Transients
 - (7) Pass/Fail Criteria
 - (8) Test Results

22.5 Test Procedures

22.5.1 Pin Injection Tests

Applied Test Waveforms:

The test waveforms used in this section are idealized waveforms in lieu of actual measured transients. A discrepancy may appear as the result of a design which is “tuned” to the idealized waveforms and their respective source impedances.

As an example, if a lightning protection circuit inside the EUT uses the relation between its predicted impedance at the test frequency and the impedance of the source (impedance divider), this same design may be defeated when presented with a waveform constituted from a combination of double-exponential and oscillatory content in an actual installation as shown in Figure 22A-1.

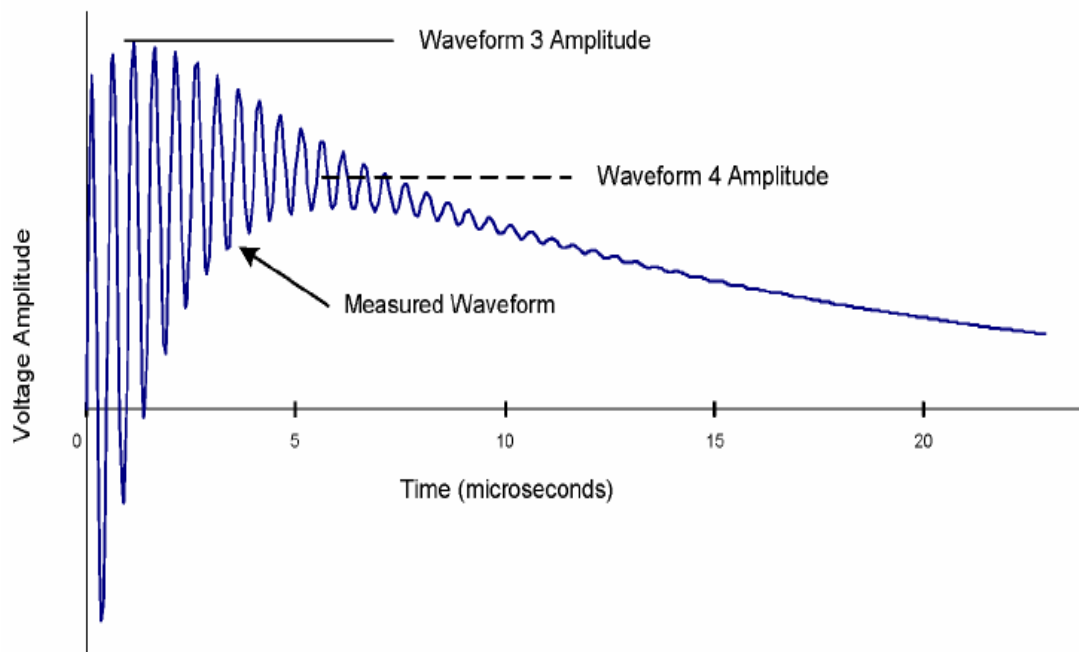


Figure 22A-1 Combined Double-Exponential and Oscillatory Waveform

For several good reasons, it is not practical, nor reasonable to require a combination test to be performed. However, consideration should be given to ensure that the design intent of the EUT takes into account the combinatory nature of the transients occurring in the real environment and the associated impedance versus frequency relationship.

a. Dielectric or high potential (hi-pot) tests

A dielectric withstand voltage or high potential (hi-pot) test may be used in lieu of the pin injection test to verify the ability of electrically simple devices such as actuators, linear variable differential transformers (LVDTs), and speed sensors to demonstrate compliance to the pin test requirements. These simple electrical devices must be passive with no EMI filters or transient voltage suppressors (or other similar electrical circuit elements that are connected through case ground to aircraft structure). In addition, the dielectric withstand voltage test is applicable for electrical devices that are electrically isolated from case and local airframe grounds. In these cases, the interface signal and return wiring must be routed together (e.g. twisted pair) in the intended installation such that an insignificant line-to-line induced voltage results. The dielectric withstand voltage test voltage level is to be at least the peak amplitude of a level in Table 22-2. Note that when testing pins which normally have a bias voltage, i.e. power line inputs or other sources, this voltage must be added to the peak test voltage of Table 22- 2. This test voltage may be applied from each pin to case or from all pins, simultaneously, to case

The aircraft installation must always be considered when choosing whether to perform a dielectric test or a pin injection test. Some aspects of the installation, such as the use of local grounds or high impedance grounds, can have a significant effect on the environment the EUT will be exposed to on the aircraft. For example, if the unit is using aircraft structure as the ground return and that return is located close to the unit (e.g. local ground), then pin injection is the appropriate test to be utilized.

Example: Dielectric Withstand Voltage Test Procedures – Typical Test Sequence

1. Connect the dielectric Withstand voltage test set between the designated pin(s) of the EUT and ground or chassis.
2. With a dielectric withstand voltage test set adjusted for the potential of the pin injection test level plus a bias voltage, take a 60 second leakage current measurement between the ground and the appropriate pin(s). The measured leakage current value shall be less than the pre determined acceptable limit.
3. Discharge the voltage stored between chassis ground and the pin(s).
4. Repeat step 2. thru 3. for each designated pin or group of pins in each connector of the EUT to which this test is to be applied.
5. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The test report should include a description of the simple device, description of the test performed, the test equipment used, etc. Other similar dielectric withstanding test procedures may also be used to perform this test.

b. Pin Injection Testing Considerations

It is required, in most cases, that the EUT is powered during pin injection, but it is not required to be connected to any external aircraft system. In this state, the software in the EUT will place its active I/O to a default state, which may not be representative of the conditions during a lightning event. Consideration should be given to the damage tolerance of interface circuitry in all potential operational states.

Figure 22A-2 illustrates a simplified circuit diagram of a Discrete Output interface, commonly called “Low-Side Switch”. In such an interface, the EUT can command the transistor, used as a switch, to either an opened or closed state. As such, the interface will possess two (2) distinct states, each of which will yield a different nature to the application of a lightning transient.

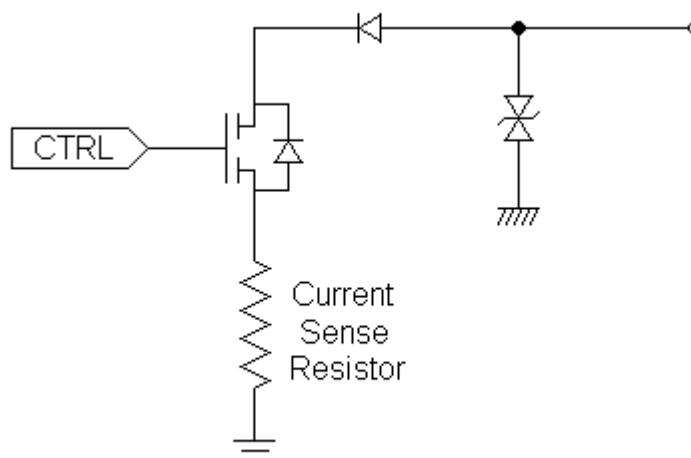


Figure 22A-2 Simplified Discrete Output Interface

Figure 22A-3 illustrates the case where a positive lightning transient would be applied to such a circuit when the transistor is commanded in the opened state. The resulting test will apply a voltage to the transistor terminals, testing its junction breakdown voltage capability. As for a Transient Voltage Suppressor (TVS) diode or any equivalent means of protection, it will be forced into breakdown and 100% of the source current will flow through this diode, resulting in a power dissipation test for that component.

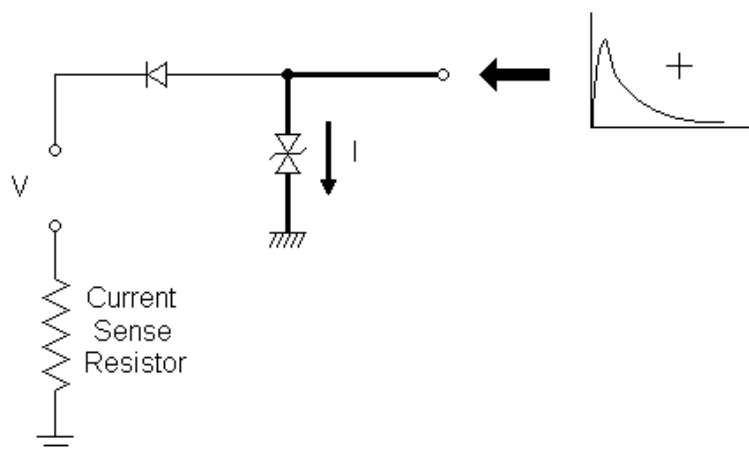


Figure 22A-3 Transient Applied on an Opened-State Circuit

In Figure 22A-4, the same transistor is in a closed state. The impedance presented to the lightning generator will now be very low, especially if the power ground plane is tied to the chassis of the EUT. In such a case, the transistor, sense resistor and series diode will all be exercised for their surge current capability. The voltage which then appears across the terminals of the sense resistor may not be sufficient, at least until the current level is very high, to turn ON the TVS diode. At that point, the TVS diode’s dynamic resistance will establish a balance of current sharing between the two branches.

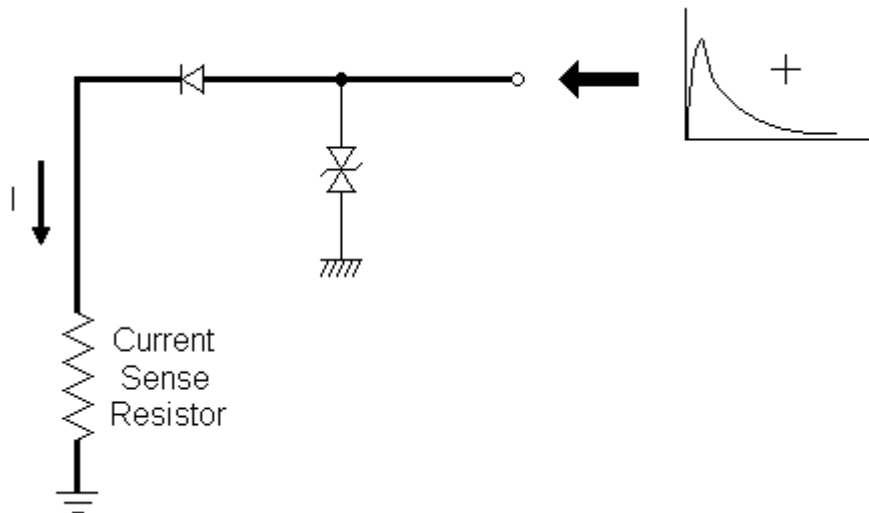


Figure 22A-4 Lightning Transient Applied to a Closed-State Circuit

Since each condition exercises different electronic component characteristics, it is conceivable that a given circuit design could tolerate the transient in one state and sustain damage with the same test applied in the opposite mode of operation.

c.

d.

e.

f. Groups (Four or more) of EUT Circuits (Pins)

When allowing the use of similarity of interfaces for qualifying untested pins, similarity should not be based strictly on schematic definition of the circuit, but consideration also given to how the artwork or printed circuit board layout potentially affects the results of the test.

Some examples:

- The printed circuit board trace width and length from the connector.
- The printed circuit board copper thickness on the layers used to route each interface.
- The number, size and type of circuit board vias used in the path of each interface.
- The spacing between each circuit component of the interface (diodes, resistors, transistors, etc.).
- The spacing between each circuit traces and pads.
- The board temperature where the circuitry is located.

Depending on the impedance of the interface, pins may see predominately voltage or current. For predominantly voltage waveform tests (high impedance input), discrete electronic components will be tested for their ability to hold voltage without sustaining damage. In this case, the formation of an arc between any two traces, vias, pads or any other adjacent artwork components should be considered. For low impedance inputs where the signal is predominantly current, discrete electronic components will be tested for their ability to conduct surge currents without sustaining damage. In this case the fusing of a copper trace used as a conductor or a via on the printed circuit board should be considered.

g.

h. Remote Load Impedance - Loading/TVSs/Impedances

Lightning transients predominately occur common mode (line to ground). Hence pin injection tests are conducted from line to ground to mimic the transient threat. As such, the common mode loop impedance will ultimately determine the loop current transient being driven by the impressed transient voltage. The following provides examples of common configurations:

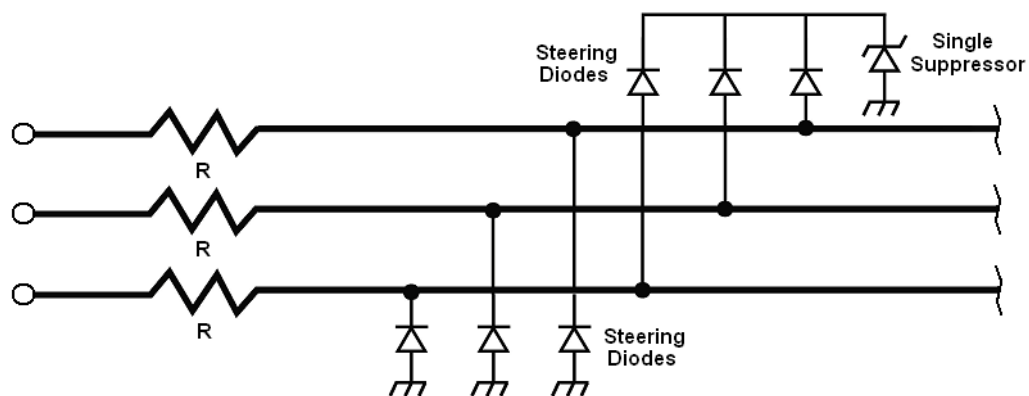
1. If either end of a circuit (at the EUT or load end) is isolated from case or aircraft ground, then, a high impedance loop exists and the current for Waveforms 4 and 5 are significantly reduced. Even if there is a TVS at one end whether it be the load or EUT, the loop impedance is still very high due to the isolation at the other/remote end. The term isolation in the remote load refers to a pin which has no electrical/electronic component installed from pin to case. This isolation is, also, only as good as the dielectric strength it is designed for. That is, if the isolated device or conductor has been designed for a 1000 V dielectric strength, the loop will remain at a high impedance when transients with a peak voltage up to that voltage, 1000V, are impressed on the circuit. In this case series impedance may be inserted between the generator and the pin to be tested. The voltage must be monitored on the EUT side (calibration point) during the pin injection tests per Figure 22-13 to ensure that the resistor has not been damaged during testing. A non-inductive resistor should be used for the series impedance to minimize the impact on the calibrated waveform.
2. If the loop forms a low impedance then there may be little to no impedance to limit the transient current. This low impedance will exist at both ends (EUT and load) of the conductor or circuit. In this case, series impedance should not be inserted between the generator and the pin to be tested.
3. If TVSs are used to provide protection and these devices are used at both the load and EUT ends, then a low loop impedance exists. That is, when, the TVSs have not “turned on” a high impedance exists. When the lightning transient voltage level exceeds the TVS clamp voltage, the TVS does “turn on” and it becomes a low impedance to shunt the loop current and minimize the voltage. Hence, if there is one at each end (EUT and load), the overall loop impedance is very low as both TVSs “turn on” and no limiting impedance exists. In this case, series impedance should not be inserted between the generator and the pin to be tested.
4. If the remote load impedance characteristics are unknown then series impedance should not be inserted between the generator and the pin to be tested.

i. Single devices used to protect multiple pins.

In some designs a single protection device may be used to protect multiple interfaces. In such cases, the single pin to case test might not account for transients appearing on multiple interfaces at the same time. An assessment of the protection device rating and/or test method may be required

For example, steering diodes might be used on several pins and would redirect the transient to a single suppressor. This implementation is typically used to save printed circuit board area as the suppressors are larger than common diodes. An example of the implementation is shown in [Figure 22A-5](#). In this case, the current path for each pin will comprise its individual series and parallel components; however the transient current of all such lines will merge into a single TVS. It must be noted that such a design methodology may or may not use identical parallel circuits prior to the suppressor, and as such, current sharing assumptions should be limited.

As an example, shown below are three EUT interfaces that are routed to three pins on the EUT connector through the use of individual steering diodes. Each pin should be tested individually to stress the individual interface components and the group of pins should be tested simultaneously to stress the common components, in this case, the TVS. This approach may not be practical from a test standpoint, as it may not be possible to inject transients on all pins of concern in a simultaneous fashion without using several synchronized generators. As such, it will become impossible to adequately test the common TVS to its intended level. Analysis should then be used to ensure that the printed circuit board features and suppressor sizing is adequate to sustain the transient current of the combined interfaces.



Typical Steering Diode Suppression Technique

Figure 22A-5 Multiple Pins Protected by a Single Device

Applied Test Waveforms:

The test waveforms used in this section are idealized waveforms in lieu of actual measured transients. A discrepancy may appear as the result of a design which is “tuned” to the idealized waveforms and their respective source impedances.

As an example, if a lightning protection circuit inside the EUT uses the relation between its predicted impedance at the test frequency and the impedance of the source (impedance divider), this same design may be defeated when presented with a waveform constituted from a combination of double-exponential and oscillatory content in an actual installation.

22.5.1.1 Procedures - Generator Calibration

a. Pin Injection Generator Calibration

Previous versions of the pin injection calibration procedure specified the use of a non-inductive resistor method of impedance verification. This method does not demonstrate the waveshape generation capability in very low or short circuit conditions. As this is the preferred method of calibration and also to eliminate discrepancies in allowable tolerances between the two methods, the resistor method was removed as a verification method. The procedure continues to specify that the voltage waveform must meet waveshape requirements, but that the short circuit current only retain the general waveshape. This implies that specified waveform tolerances may be exceeded for short circuit current, which is due to limitations of some waveform generators. It is the intent of the test to deliver an equivalent amount of energy to the circuit under test and that this be consistent regardless of the generator being used. As such, deviations from the specified waveshapes should be minimized as much as possible. In cases where the short circuit current waveshape is not within specified tolerances the following guidance applies: For double exponential short circuit current waveforms, if T2 (decay time) is longer or T1(risetime) is shorter, the waveshape is acceptable. If the decay time is shorter than T2 minus 20%, it is recommended that the test level be increased such that the T2 current is equal to 50% of the specified peak, not the measured peak. Likewise if the risetime is longer than T1 plus 20%, the test level should be increased such that the specified peak current occurs within that time period.

Additional Generator Pin Injection Source Impedance Verification

This is an additional verification check for the unlikely event that a generator would pass V_{OC} and I_{SC} but fail a resistor test for Pin Injection source impedance verification for example, if the generator is not linear.

In addition to the V_{OC} and I_{SC} tests defined in Section 22.5.1.1 to verify the generator pin injection source impedance at both extremes (V_{OC} , I_{SC}), a user can use a non-inductive resistor load as additional verification of the generator's pin injection source impedance.

This additional verification step would only need to be done once to verify that the generator output is designed correctly or if the user suspects a generator issue. This need not be performed continually for calibration or testing.

1. Set/measure the open circuit voltage of the generator/test leads at the V_{OC} test level with no resistor load.
2. Place a non-inductive resistor load (R) equal in value to the test waveform specified source impedance (V_{OC}/I_{SC}) on the output of the generator/test leads.
3. Measure the voltage drop across the non-inductive resistor (V_R) with the generator at the same setting that produced the required V_{OC} in step 1 above. This voltage must be $V_{OC}/2 \pm 5\%$ if the non-inductive resistor load (R) is within 1% of the test waveform specified source impedance (V_{OC}/I_{SC}). If R is greater than 1% of the test waveform specified source impedance (V_{OC}/I_{SC}), then compensate for R resistance error by using Ohm's law to determine if the actual generator source impedance (Z_{GEN}) is within $\pm 10\%$ of the specified (V_{OC}/I_{SC}).

$$Z_{GEN} = (V_{OC} * R / V_R) - R$$

Z_{GEN} = generator source impedance (Ohm)

V_{OC} = generator/test lead open circuit output voltage (Volt)

R = non-inductive resistor (Ohm)

V_R = Voltage measured across R (Volt)

For example, if you were performing a waveform 4, level 3 calibration, you would set the unloaded generator/test leads to produce a V_{OC} of 300 Volts and then place a <1% non-inductive 5 Ohm resistor (R) across the generator/test lead output and verify the voltage measurement across the resistor is 150 Volt +5% or if the non-inductive 5 Ohm resistor is greater than 1% tolerance (as measured with precision Ohmmeter), use the formula above to determine if the actual generator source impedance (Z_{GEN}) is 5 Ohm +10 %.

- b.
- c.
- d.

22.5.1.2 Procedures - Test Sequence

- a.
- b.
- c. There is no required minimum time interval between pin injection transient applications. Waveform 3 is not considered a thermal stress concern, however, a minimum interval (not to exceed one minute) should be considered for the double exponential waveforms to avoid undue thermal stress.
- d.
- e.
- f.
- g.
- h.
- i.
- j.
- k.
- l.

22.5.2 Cable Bundle Tests

- a. An interconnect cable bundle to be tested is typically associated with one connector, with the exception of power leads which are not necessarily included with the connector's cable bundle.

Power leads are tested separately when aircraft installed power routing is different than the other interconnect wiring or is unknown. When a connector includes multiple power leads, such as DC power with remote return, AC power with remote return, or three phase AC power, the worst case typically is to test each power lead separately (including testing the remote returns separately), limiting the current level to the pin injection current level and

then test the signal bundle without power leads. However, there are situations in which DC power leads should be tested both separately as well as together as an additional test to ensure the worst case is covered. For example, equipment may utilize multiple DC power line inputs fed from different power sources, whether entering one connector or multiple connectors, for reasons such as redundancy. In this situation, the power lines should be tested together, and the test current increased to the number of power sources multiplied by the appropriate current test level. If multiple wires feed the power supply from the same source, as is the case where multiple wires are used to carry the power current using smaller gauge wire, then these wires should be tested together but the current limit does not exceed that of a single power wire. Grouping multiple interconnect cable bundles together during the cable induction test may not induce sufficient current in each individual interconnect cable bundle to satisfy installation requirements and therefore, is not recommended.

DC isolation of a remote load connected with a specific wire bundle is not sufficient justification to eliminate the cable bundle testing of that particular wire bundle because some level of differential mode transients may still be developed.

- b.
- c.
- d.
- e.
- f.
- g. During the cable bundle test, if the limit level (I_L or V_L) is reached before the test level (I_T or V_T) the procedure (paragraph 22.5.2.1.2i (1)) requires that the test must be evaluated for validity. If the generator used does not meet the specified limit criteria, the procedure states that a different waveform generator must be selected to complete the test.

When performing a current test, using WF1 and/or WF5, it is desirable to reach the current test level (I_T). For a low impedance wire bundle, this typically is not an issue and the I_T requirement is reached well before the voltage limit (V_L). However, in the event V_L is reached before the I_T , the user may be required to change generators. In this case, the user may elect to continue to increase the current waveform generator level before changing generators, depending on the level of over test that is acceptable. By increasing the generator level to I_T and evaluating performance at that level, the shielded waveform category and test level designation can be retained.

It is recognized that in many cases, this is not possible and that simply increasing the generator level until I_T is reached may be an overly severe test.

In a limited number of cases, such as those presented with a “hybrid wire bundles” (high impedance but with limited number shields), it is possible to fulfill the ‘requirements’ of the test, i.e. reach V_L with a compliant Waveform 2 or Waveform 4 generator, while not meeting the full intention of the test, which is to transfer the required power onto the bundle. One reason for this involves the method used to measure the voltage across the injection transformer’s open loop. Current flow through the secondary winding of the transformer (i.e. the cable bundle under test) can result in an artificially high open loop voltage measurement relative to the voltage transferred onto the core wires of the actual EUT interface.

If the voltage waveform has been shown to be compliant during the current test generator performance verification and the V_L is reached during the test, this is

considered to be a valid test. However, as discussed above, this does not necessarily result in the proper core wire voltage and again, does not fulfill the overall intention of the tests. If driving the current waveform generator to I_T is considered too severe, it is suggested that the power from the generator be increased, exceeding the compliant Waveform 2 or Waveform 4 V_L , until the current level reached is at least 75% of the I_T . If this also results in an increase in power from the generator such that the compliant Waveform 2 or Waveform 4 voltage level is excessive and there is a threat of equipment damage, it is suggested that the shields be removed and a voltage test conducted using the appropriate voltage waveform (Waveform 2 or Waveform 4) and test level requirements.

Achieving an acceptable level of induced current in a shielded cable bundle can be very challenging on hybrid cable bundles, which by definition can include only a single shielded wire. If the user attempts to meet the intent of the test by following the process described above and continues to drive the generator to excessively high levels without meeting the suggested levels, then the selected waveform set should be re-evaluated as they are likely not valid for the proposed installation.

This process is depicted in Figure 22A-6.

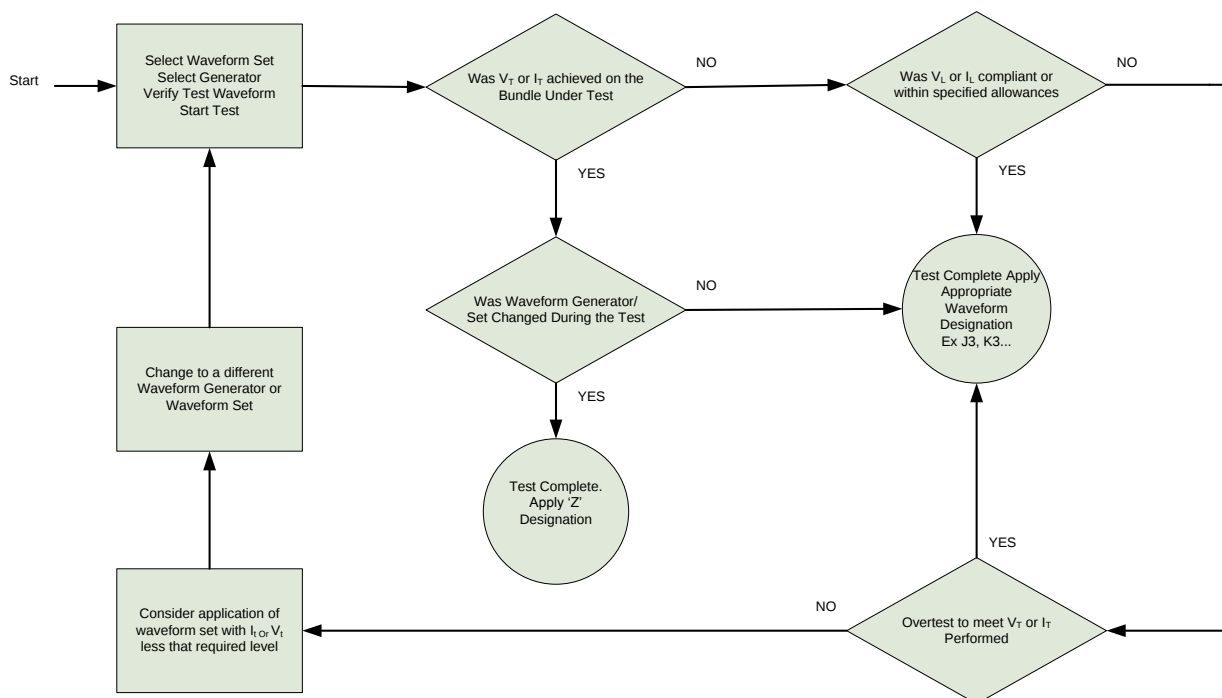


Figure 22A-6 Waveform Test Process

The voltage magnitude associated with each test level is the same for the pin injection tests and the cable bundle tests. The associated currents for cable bundle testing are higher because they reflect injection on multiple conductors rather than the single conductor for pin injection. When testing an individual conductor using cable induction, it should be recognized that this is normally a more severe test, in that the test generator is adjusted to meet the test level (V_T or I_T) as opposed to the controlled source impedance generator methodology used for pin injection. Note that as specified in the test requirements, the only situations in which a conductor is expected to be tested individually are the cases of power leads and of single

conductor connectors.

When a cable bundle contains a relatively low wire count, the cable bundle test may also be more severe than the pin injection test because there are fewer wires to distribute the induced cable current. The wire count where this severity threshold occurs is dependent upon the waveform that is being applied. For example, the Waveform 1 current test level (I_T) is a factor of 10 times the corresponding Waveform 4 pin injection short circuit current (I_{SC}). In the case of Waveform 5A, the ratio varies from 2.67 to 3.33 times the individual pin I_{SC} , depending on the test level selected.

Where cable bundle test individual conductor currents could significantly exceed the pin injection test I_{SC} , such that overstressing pins is a concern, the percentage of the total current may be scaled to not exceed the individual pin short circuit current level. If the user scales the current, this may be acceptable for the proposed installation; however, a standard cable bundle test has not been performed and the test level designation must be designated as a 'Z'. There should be no distinction between shielded or unshielded wires when establishing the number of conductors for scaling purposes.

Antennas represent a case where there may be a connector with a single conductor. Since antennas are normally installed in high threat areas, scaling the current is not recommended.

- h.
- i.

(1)

(2)

(3) Applicability of Waveform 6

Current Waveform 6 is present as a response to current component H in the lightning multiple burst waveform set. Current Waveform 6 will be present on the shields of well terminated, e.g. 360 degree shield to connector terminations, shielded cables interconnecting system equipment. Also, in order for current Waveform 6 to be the response to current component H, loop areas and impedances (cable lengths, connector termination, low impedance enclosure connections to the "ground plane", etc) must be small enough that in the frequency domain, the transfer function, for current component H to current Waveform 6 coupling, is flat. In other words, the frequency content of current Waveform 6 will be that of current component H over the current component H range of frequencies of interest.

If loop areas and impedances are such that current Waveform 6 will not be the response, the rise time of current component H is fast enough that interconnecting cable lengths will appear to be "electrically" long or impedance mismatched and the response will be voltage/current Waveform 3.

Low Impedance cables that may require Waveform 6 application are typically located in regions of the aircraft that are electromagnetically exposed or where resistive coupling may predominate. Examples of regions where Waveform 6 may need to be evaluated include landing gear regions, engine installations, flight control surfaces, wingtips, or empennage regions. Generally, regions within the fuselage or wing structures will not have significant coupling of the Waveform 6.

22.5.2.1 Cable Induction Tests

22.5.2.1.1 Procedures - Generator Performance Verification

- a.
- b.
- c.

22.5.2.1.2 Procedures - Test Sequence

- a.
- b. It may be necessary to pass the cable bundle under test through the injection transformer for multiple turns in order to reach the voltage test level (V_T) during the EUT test. For accurate voltage measurements, the open voltage monitor loop number of turns must match the EUT cable bundle number of turns. The default, as shown in Figure 22-17, is one turn (1 pass), which is adequate in most test situations. However, it is acceptable, for voltage waveforms only, to increase the voltage to current ratio by using multiple EUT cable bundle and open voltage monitor loop turns. This technique should never be used to reach the voltage limit (V_L) during current waveform tests.
- c.
- d. **Transient Amplitude Determination**

Introduction

Transient amplitude determination can be a significant source of test variability and error. The techniques used not only determine the susceptibility threat level applied to the EUT, they are also the basis of timing measurements that determine whether the waveshape is compliant during generator calibration/verification. Variability and error can be minimized by using consistent oscilloscope measurement techniques when making transient measurements. The following guidelines are intended to assist with transient amplitude determination when using a digital storage oscilloscope:

- a. Use cursors, not automatic measurement functions.
- b. Select the proper time scale.
- c. Properly place cursors in the presence of high frequency noise and loading effects.

Use of Cursors

Whenever a voltage or current transient amplitude measurement determines the level applied to the EUT, including the pin injection test's generator calibration, cable bundle test's generator performance verification, and cable bundle test's test sequences, peak amplitude should be determined by manually placing the oscilloscope's horizontal cursors rather than by using automatic measurement functions which just report the absolute peaks. For the pin injection test's test sequence, amplitude is measured for information only, so automatic measurement functions are always acceptable because the level applied to the EUT has already been determined by that point.

The possibility of under-testing is the reason the use of cursors is advisable when the measurement determines the level applied to the EUT. Transient characteristics described in this section such as high frequency noise and the inductive kick effect, which are not uncommon, cause the absolute peak of the transient to be higher than the actual transient amplitude. If a transient is free of these characteristics, both measurement techniques will yield the same amplitude.

Time Scale Selection

The second key to consistent transient amplitude measurements is to choose the proper time scale. This improves consistency in the identification of high frequency noise versus the transient being measured.

During generator calibration/generator performance verification, the time scale should be set to the minimum time per division which displays all of the waveform parameters necessary to show compliance. For example, for most oscilloscopes, 1 μ s per division is the minimum time scale which displays the required waveform parameters for Waveform 3 at 1 MHz per [Figure 22-4](#). Depending on transient generator design, the open circuit voltage and short circuit current time scales may be different.

During the cable bundle testing EUT test sequence, the same time scale established during generator performance verification for the voltage or current that is leveled to should be maintained. With Waveform 1, when I_T is reached prior to V_L use the time scale established during short circuit current, for example 10 or 20 μ s per division would be appropriate. When V_L is reached prior to I_T , use the shorter time scale established during open circuit voltage, such as 4 μ s per division.

Cursor Placement in the Presence of High Frequency Noise and Loading Effects

High Frequency Noise

One transient characteristic that may appear during generator calibration/generator performance verification or as a loading effect during the EUT test sequence is high frequency (high with respect to the intended transient's frequency components) noise. High frequency noise can appear on the leading edge and/or peak of both damped sine and double exponential waveforms and it should be ignored/not given credit.

[Figure 22A-7](#) is an example of correct amplitude determination of a Waveform 3 damped sine transient with high frequency noise. The narrow spike on the peak of this transient's first cycle is the high frequency noise which should be ignored during amplitude determination. The narrow spike gradually opens as amplitude decreases, requiring a subjective judgment of where to place the cursor. The narrow spike should be minimized or not exist during the generator calibration/generator performance verification, but may be unavoidable as a loading effect during the EUT test sequence. As shown in this example, place the cursor at the peak where there is some discernible energy under the curve. This discernible energy under the curve amplitude determination criterion illustrates the importance of time scale choice.

Figure 22A-8 is an example of correct amplitude determination of a Waveform 4 double exponential transient with high frequency noise. Loading effect high frequency noise is present both as the narrow spikes on the leading edge and peak of the transient and as a hash around the decay of the transient. Since the double exponential test transient is masked by high frequency noise, a curve was drawn to represent the test transient based on the general underlying waveshape, which may differ from the generator calibration/generator performance verification waveshape. As shown in this example (and similar to Figure 22A-7), place the peak amplitude cursor at the peak of the curve representing the test transient. Understand that there is energy under the curve which is masked by the noise, in order to avoid overly conservative cursor placement at the base of the noise. The curve representing the test transient may be drawn on a printed waveform or may only be drawn mentally by an experienced operator. Ideally, transient generators do not produce even close to this amount of high frequency noise during generator calibration/generator performance verification, but some amount may be present. In this case, base the 50% amplitude point which determines T2 on the peak amplitude cursor.

In both of these examples, the subjective judgment of the test operator is required, but that is unavoidable. The use of an automatic measurement function for either transient would result in amplitude over-reporting, an unacceptable under-test if the measurement determines the level applied to the EUT. Careless cursor placement can result in amplitude under-reporting, an unnecessary over-test.

Loading Effects

In general, amplitude determination of transients with loading effects is no different than amplitude determination of transients that follow the ideal damped sine or double exponential waveforms: the peak of the transient is the amplitude if there is discernible energy under the peak.

For example, Figure 22A-9 is a Waveform 5A double exponential transient with two notable loading effects- ripple and high frequency noise. Ripple should only be present as a loading effect, not during generator calibration/generator performance verification, if the generator is well designed. Ripple can appear on damped sine and double exponential waveforms, with or without higher frequency spikes included. Like most other loading effects, the peak of the test transient is the peak of the ripple, but high frequency noise should still be ignored. In this example, the upper cursor gives credit for the high frequency noise and is therefore incorrect amplitude determination that results in an under-test. The second cursor is correct amplitude determination because it ignores high frequency noise as described above, yet gives credit for the peak of the ripple. Like Figure 22A-8, a curve was drawn between the peaks of the ripple as another example of representing the test transient based on the general underlying waveshape, which may differ from the generator calibration/generator performance verification waveshape.

The most common damped sine loading effect is the inductive kick effect, which arises because of the ability of inductance in the load circuit (EUT) to store energy initially upon discharge of the transient generator. The stored energy is released later in the cycle, increasing the charge on the generator's tank capacitor above the open circuit level. The result is subsequent peak(s) of higher amplitude than the first peak and of higher amplitude than the generator was charged to, as shown in Figure 22A-10. Amplitude determination of the inductive kick effect is a special case. The procedure below is a best practice for determining the method to level the generator and determine amplitude:

Increase the generator amplitude until the verification peak is equal to the requirement or until the highest subsequent peak is equal to the requirement + 20%. In other words, exceed the requirement by up to 20% in an attempt to meet the requirement with the first peak. Record the amplitude of the highest peak the selected polarity, which is at some amplitude between the requirement and the requirement + 20%.

Figure 22A-10 is an example of a positive polarity Waveform 3 cable bundle test. . Since the second positive peak is more than 20% higher than the first positive peak, record the amplitude of the second positive peak, which is currently at the requirement level + 20%.

Figure 22A-11 is an example of a negative polarity Waveform 3 cable bundle test.

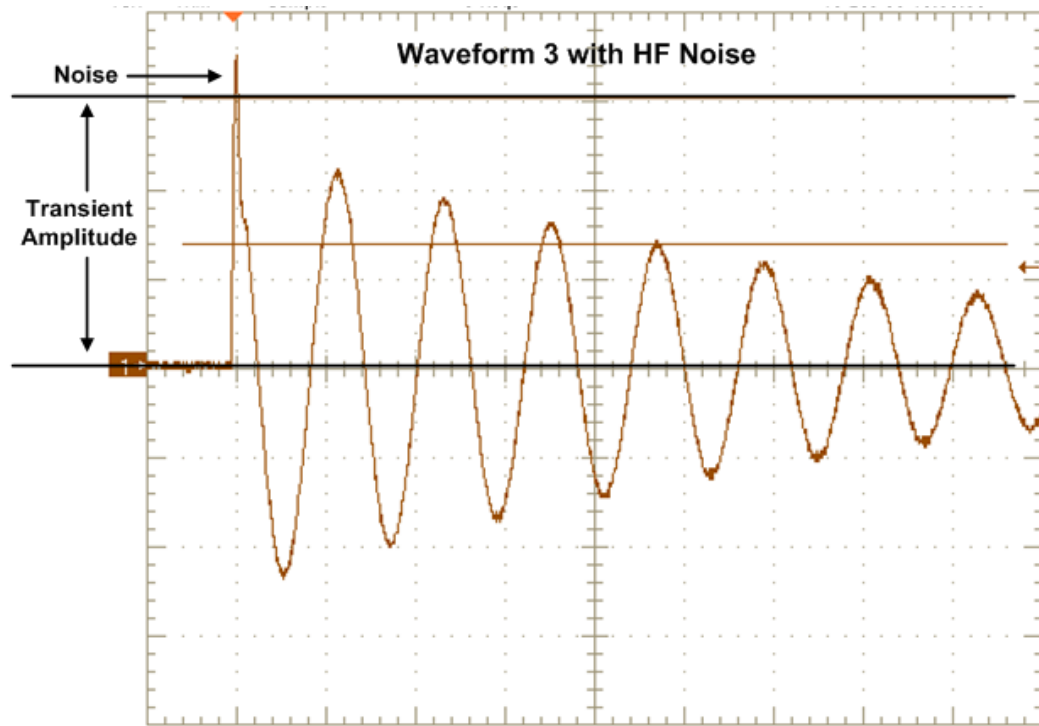


Figure 22A-7 High Frequency Noise - Waveform 3 Amplitude Determination

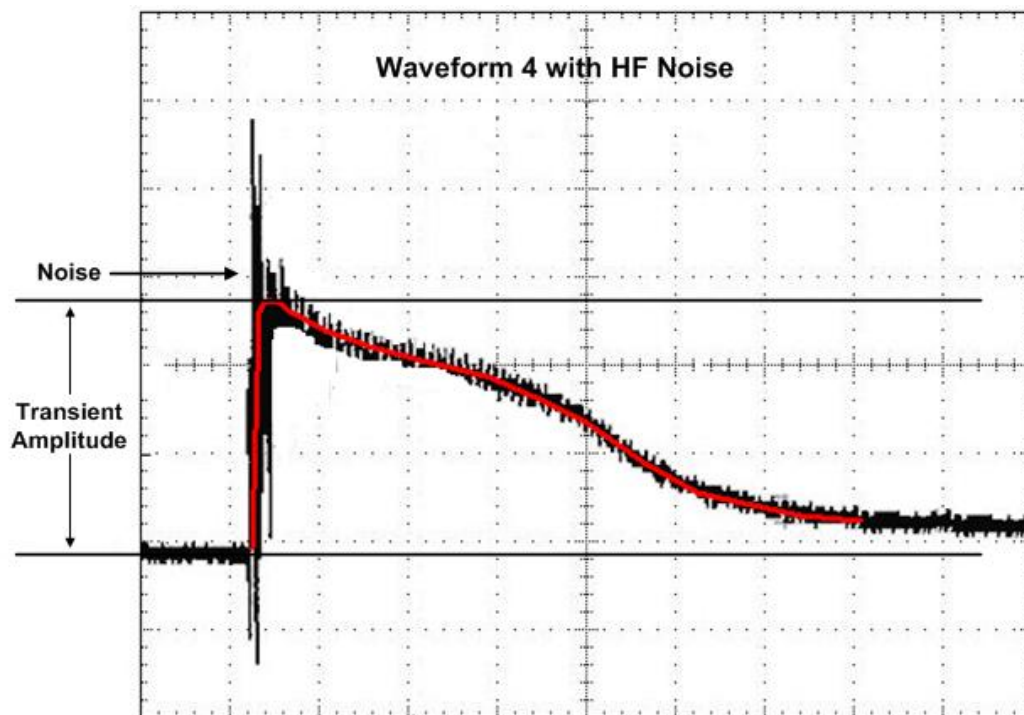


Figure 22A-8 High Frequency Noise - Waveform 4 Amplitude Determination

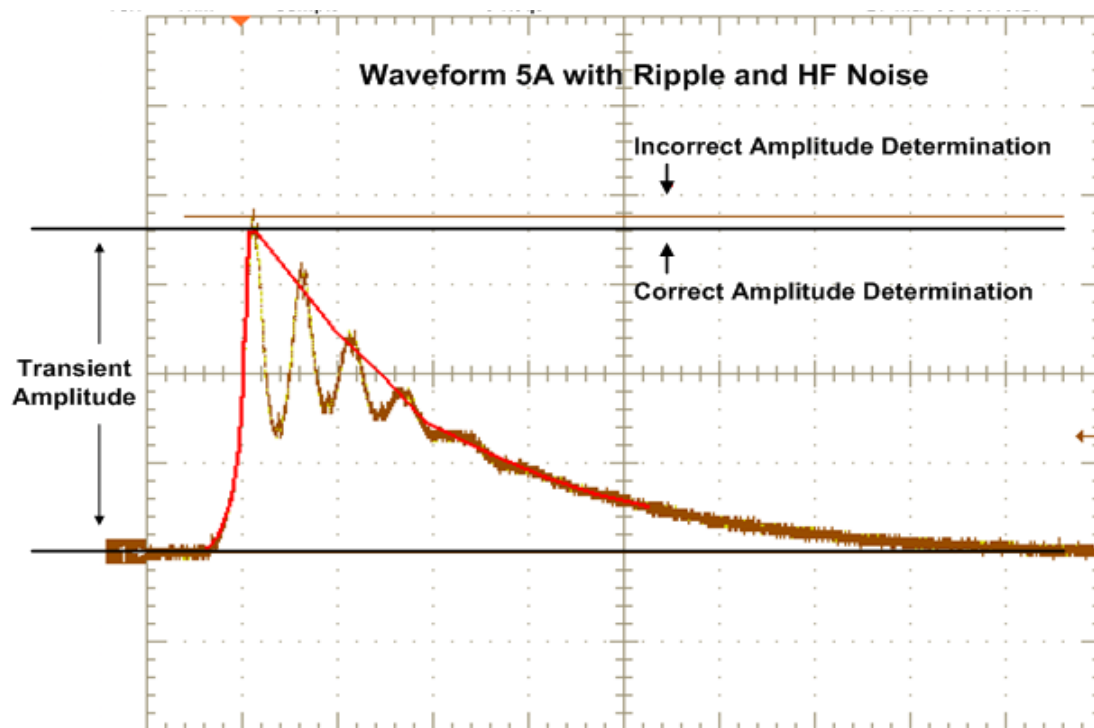


Figure 22A-9 Ripple with HF Noise - Waveform 5A Amplitude Determination

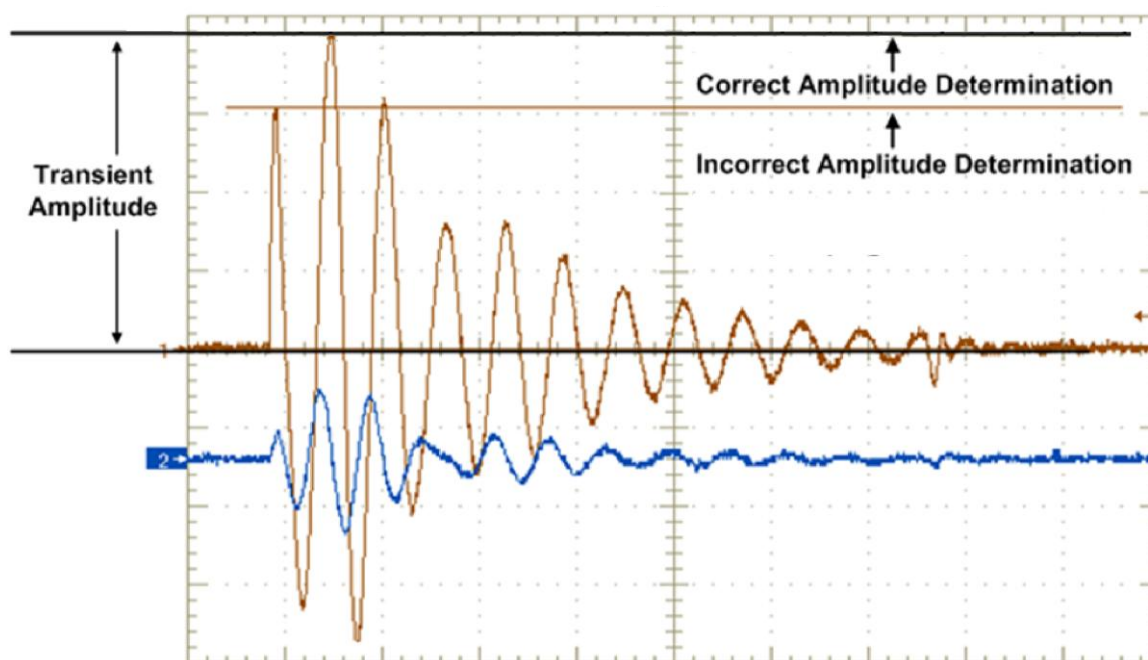


Figure 22A-10 Positive Inductive Kick Effect - Waveform 3 Amplitude Determination, Positive Polarity Applied

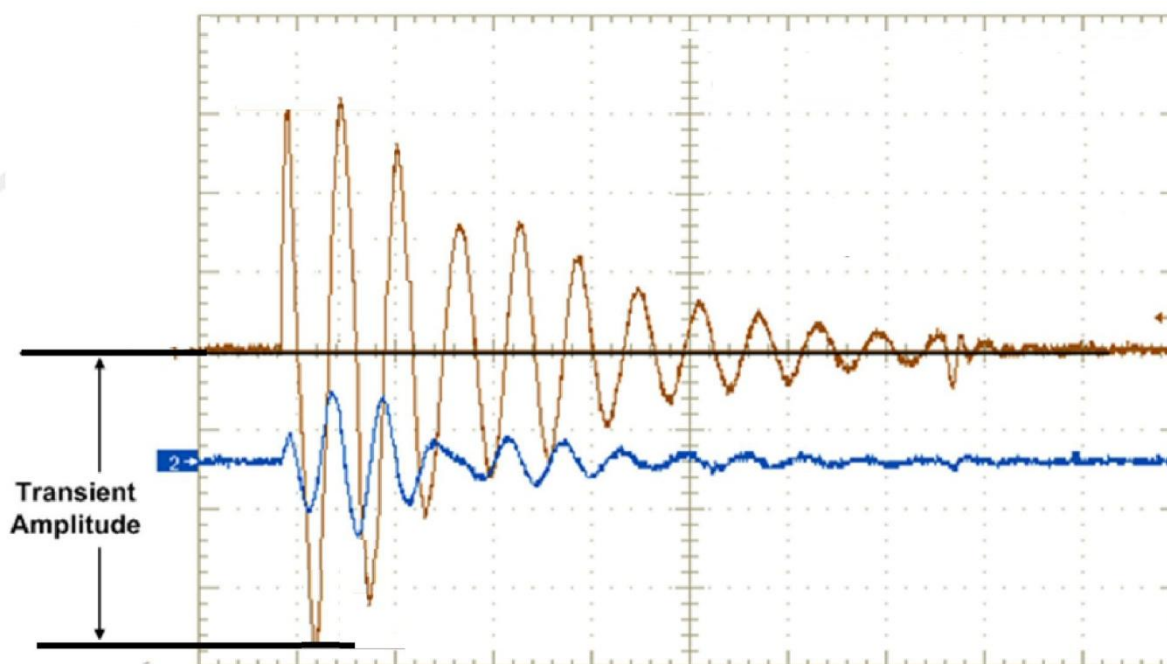


Figure 22A-11 Negative Inductive Kick Effect - Waveform 3 Amplitude Determination, Positive Polarity Applied

- e.
- f.
- g.
- h.
- i.

- j.
- k.
- l.

22.5.2.2 Ground Injection Tests

22.5.2.2.1 Procedures - Generator Performance Verification

- a.
- b.

22.5.2.2.2 Procedures - Test Sequence

- a.
- b.
- c.
- d.
- e.
- f.
- g.
- h.
- i.
- j.
- k.
- l.

Table 22-1.1 Pin Injection Test Requirements

Table 22-1.2 Cable Bundle Test Requirements

Table 22-3 Test and Limit Levels for Cable Bundles Single Stroke Tests

Table 22-4 Test and Limit Levels for Cable Bundle Multiple Stroke Tests

Table 22-5 Test Levels for Cable Bundle Multiple Burst Tests

Figure 22-1 Current Waveform 1

Figure 22-2 Voltage Waveform 2

Figure 22-3 Voltage/Current Waveform 3

Figure 22-4 Voltage Waveform 4

Figure 22-5 Current/Voltage Waveform 5

Figure 22-6 Current Waveform 6

Undershoot of Double Exponential Waveforms

Section 22 figures show idealized double exponential waveforms which do not define undershoot. Equipment manufacturers should be aware that significant undershoot may occur in actual aircraft installations and may also occur as a by-product of the cable bundle test method. If this occurs during cable bundle testing as a result of the natural response of the cable bundle to the applied waveform (the undershoot was not present during generator calibration), this undershoot should not be limited with an external clamping device on the test setup.

Figure 22-7 Multiple Stroke Application

Figure 22-8 Multiple Burst Application

Figure 22-9 LISN Input Impedance Characteristic

Figure 22-10 Pin Injection Calibration Setup, Signal Pins & Power Pins – Direct Injection Method

Figure 22-11 Pin Injection Calibration Setup, Power Pins – Cable Induction Method

Figure 22-12 Pin Injection Calibration Setup, Power Pins – Ground Injection Method

Figure 22-13 Pin Injection Test Setup, Signal Pins & Power Pins – Direct Injection Method

Figure 22-14 Pin Injection Test Setup, Power Pins - Cable Induction Method

Figure 22-15 Pin Injection Test Setup, Power Pins - Ground Injection Method

Figure 22-16 Typical Generator Performance Verification Setup for Cable Induction Tests

Figure 22-17 Typical Cable Induction Test Setup

Figure 22-18 Typical Generator Performance Verification Setup for Ground Injection Tests

Figure 22-19 Typical Ground Injection Test Set-up

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 23

Lightning Direct Effects

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2, and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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23.0 Lightning Direct Effects

23.1 Purpose of Tests

The tests described in this section are intended to determine the ability of externally mounted equipment to withstand the direct effects of a lightning strike. The term “externally mounted equipment” refers to all equipment mounted externally to the main skin of the aircraft and includes all such equipment that is covered only by a dielectric skin or fairing that is an integral part of the equipment. It also includes connecting cables and associated terminal equipment furnished by the equipment manufacturer as a part of the equipment.

The tests described herein specifically exclude the effects on the tested equipment of voltages and currents induced into the externally mounted equipment and its associated circuitry by means of magnetic or electric field coupling. These indirect effects are covered in Section 22.

Examples of equipment covered by this section are antennae, exterior lights, air data probes, external sensors, and anti-ice and de-ice equipment which are mounted external to the structure (i.e. electrically heated anti-ice boots), magnetic fluid level indicators, fuel filler caps and drain valves.

Examples of equipment typically not covered by this section are equipment that are an integral part of the aircraft structure (i.e., heated or unheated windshields, electrically de-iced leading edges where the de-ice system is an integral part of the leading edge structure or is enclosed by the leading edge structure), and externally mounted equipment that is protected by aircraft nose radomes or dielectric coverings which are specific to the aircraft structure and are not integral with the equipment itself. Components such as these typically are to be addressed and/or tested as a part of the airframe lightning certification program specified by the aircraft manufacturer, or by other test method(s) appropriate to the component being qualified.

Two types of direct effects tests are contained in the section: High voltage strike attachment tests and high current physical damage tests. The high voltage strike attachment test is used to determine likely lightning attachment locations on the test object. The high current physical damage test is used to determine the damage that may occur to the test object during a lightning channel attachment to or near the test object. The high current physical damage test can be used to assess:

- Arc root damage.
- Hot spot formation.

- Melt-through behavior.
- Adequacy of protection.
- Behavior of joints (sparking and damage).
- Level of voltage and current induced on electrical conductors interfacing with test object.

Typically, high voltage strike attachment tests are performed first to determine the likely lightning attachment locations on the test object. The high current physical damage test is then applied to an attachment location identified during the high voltage testing. Test objects that do not have a dielectric covering may not require high strike voltage attachment tests prior to the high current testing if the likely lightning attachment points can be identified. In such cases the test plan shall define the location on the test object where the high current is to be applied.

Normally the equipment will not be powered up or operating during the tests described herein. In situations where a power-on condition could change the susceptibility of the equipment to the direct effects of lightning, the equipment should be powered up or, alternatively, a means employed to simulate the powered up condition. The need for power or a simulated power condition shall be defined in the test plan.

In some situations it is necessary to evaluate the potential interactions of the test object with other aircraft systems during a lightning attachment. Two types of interactions commonly evaluated are:

- The characteristics of voltages that are directly injected into the test object wiring and passed along to other aircraft electrical/electronic systems, and
- The potential for arcs/sparks from a test object located in a fuel vapor area.

This section provides procedures for detecting arcing and sparking which may ignite a 200 microjoule sensitive fuel mixture and measuring directly injected voltages onto the test object wiring. The need for these procedures shall be defined in the test plan.

Externally mounted fuel equipment require additional detection techniques to ensure they do not create any ignition sources with an energy greater than or equal to 200 microjoules. Section 24.3.4.1 describes how to apply the test methods of this section to externally mounted fuel components. The purpose of these tests as applied to fuel components is determine if a strike to the component can create an ignition source. The tests in this section do not apply to combustion containment, flame propagation or pressure surges due to combustion. Thus the ignition source detection methods described in this section do not apply to propagation prevention components such as flame arrestors. Tests to components such as NACA vents, where flame

propagation or flame overpressures need to be evaluated, hydrogen-argon mixtures are not appropriate, and hydrocarbon mixtures should be used.

A flow chart giving the sequence of testing is shown in Figure 23–1.

23.2 Definitions

Action Integral

The integral of the square of the time varying current over its time duration. It is usually expressed in units of ampere-squared seconds (A^2s).

Arc Root

The location on the surface of a conducting body at which the lightning channel is attached while high current flows.

Attachment Point

Point of contact of the lightning flash with the aircraft.

Continuing Current

A low level long duration lightning current that occurs between or after the high current strokes.

Corona

A luminous discharge that occurs as a result of an electrical potential difference between the aircraft and the surrounding atmosphere.

Direct Effects

Any physical effects to the aircraft and/or equipment due to direct attachment of the lightning channel and/or conduction of lightning current. This includes dielectric puncture, blasting, bending, melting, burning and vaporization of aircraft or equipment surfaces and structures. It also includes directly injected voltages and currents in associated wiring and plumbing, and other conductive components.

Discharge

The transfer of charge from the high voltage or high current impulse generators.

First Return Stroke

The high current surge that occurs when the leader completes the connection

between the two charge centers. The current surge has a high peak current, high rate of change of current with respect to time (di/dt) and a high action integral.

Flashover

The condition when the arc produced by a gap breakdown passes over or close to a dielectric surface without puncture.

Gap Breakdown

The electrical breakdown of the gap between the electrodes connected to the generator output terminals. This breakdown is caused by the discharge of the capacitors of a high voltage or high current impulse generator.

Hot Spot

A surface in contact with fuel/air mixtures that is heated by the conduction of lightning currents to a temperature which will ignite the mixtures.

Intermediate Current

A current of several milliseconds duration whose amplitude (namely a few kA) is higher than the range of continuing currents and lower than the range of stroke currents.

Leader

A low luminosity, low current precursor of a lightning return stroke accompanied by an intense electric field.

Lightning Flash

The total lightning event. It may occur within a cloud, between two clouds, or between cloud and ground. It can consist of one or more return strokes, plus intermediate or continuing currents.

Lightning Strike

Any attachment of the lightning flash to the aircraft.

Lightning Strike Zones

Aircraft surface areas and structures classified according to the possibility of lightning attachment, dwell time and current conduction. See ARP5414/ED-91 for reference.

Lightning Stroke (Return Stroke)

A lightning current surge that occurs when the lightning leader makes contact with the ground or another charge center.

Puncture

Localized irreversible breakdown of insulation properties of a solid dielectric material.

Streamers

Branch-like ionized paths that occur in the presence of a direct stroke or under conditions when lightning strokes are imminent.

Swept Channel

The lightning channel relative to the aircraft, which results in a series of successive attachments due to sweeping of the flash across the aircraft by the motion of the aircraft.

Swept Leader

A lightning leader that has moved its position relative to an aircraft, subsequent to initial leader attachment, and prior to the first return stroke arrival, by virtue of aircraft movement during leader propagation.

Thermal Sparks

Burning particles emitted by rapid melting and vaporization of conductive materials carrying current through a point contact.

Voltage Spark

An electrical breakdown of a gaseous dielectric between two separated conductors.

23.3 Equipment Categories

The nature and severity level of the tests to be applied to externally mounted equipment will depend upon the designated categories of that equipment. The designated test categories for the equipment should correspond to the lightning strike zone in which the equipment is located. The category designations for equipment shall consist of four letters:

- the first two characters designate the High Voltage Strike Attachment Test Category, and

- the third and fourth characters designate the High Current Physical Damage Test Category.

Category designation should, therefore, appear as follows:

<u>2A</u>	<u>2A</u>
High Voltage	High Current
Strike Attachment	Physical Damage
Test Category	Test Category

If no high voltage strike attachment tests are performed then the first two letters would be XX. If high current physical damage tests are not performed then the third and fourth letter would be XX. If no tests are performed the category designation is XXXX.

If the high voltage or high current tests are performed using waveforms or a test configuration that was different from that designated in this section, then the category designation ZZ is to be used. For example, a high voltage strike attachment test using a non-standard waveform followed by a high current physical damage test to Category 1A has the category designation ZZ1A. When Category ZZ is used, the specific test conditions and test levels shall be described in the test report.

The following are descriptions of each of the standardized Test Categories:

Category 1A

Intended for equipment externally mounted in those areas of the aircraft identified as Lightning Zone 1A. Zone 1A is all areas of the aircraft surface where a first return stroke is likely during lightning channel attachment with a low expectation of flash hang on.

Category 1B

Intended for equipment externally mounted in those areas of the aircraft identified as Lightning Zone 1B. Zone 1B is all areas of the aircraft surface where a first return stroke is likely during lightning channel attachment with a high expectation of flash hang on.

Category 1C

Intended for equipment externally mounted in those areas of the aircraft identified as Lightning Zone 1C. Zone 1C is all areas of the aircraft surface where a first return stroke of reduced amplitude is likely during lightning channel attachment with a low expectation of flash hang on.

Category 2A

Intended for equipment externally mounted in those areas of the aircraft identified as Lightning Zone 2A. Zone 2A is all areas of the aircraft surface where subsequent return stroke is likely to be swept with a low expectation of flash hang on.

Category 2B

Intended for equipment externally mounted in those areas of the aircraft identified as Lightning Zone 2B. Zone 2B is all areas of the aircraft surface into which a lightning channel carrying a subsequent return stroke is likely to be swept with a high expectation of flash hang on.

Category 3N

Intended for equipment externally mounted in those areas of the aircraft designated as Lightning Zone 3 which have new or novel design features that could significantly reduce the level of protection provided by traditional designs, or which have no proven service history.

23.4 General Test Procedures

High voltage strike attachment and high current physical damage test procedures are described in this section. High voltage tests are applied to determine the places where lightning may attach to equipment and to verify adequacy of protection for non-conductive materials. High current tests are applied to verify ability of equipment to tolerate lightning currents.

WARNING

Lightning simulation tests require high energy electrical equipment which may be charged to very high voltages during their operation. Therefore, all safety precautions relevant to this type of test apparatus should be complied with. All tests should be conducted in a controlled access area by personnel experienced in high voltage/high current testing.

23.4.1 High Voltage Strike Attachment Testing

Two types of high voltage tests are described in this section. The type of high voltage test performed on a test object is dependent upon its test category requirement. Initial leader attachment tests are used to determine likely lightning attachment locations for a piece of equipment due to an approaching lightning leader. Swept channel attachment tests determine the likely lightning attachment locations for a piece of equipment due to a lightning channel sweeping across equipment. Table 23-1 provides a summary of the test types and the associated high voltage test waveform applied for each test category.

Table 23-1 – High Voltage Test Types and Test Waveforms

High Voltage Strike Attachment Test Category	Test Type	High Voltage Waveform	
		A	D
1A	Initial Leader Attachment Test (23.4.1.2)		X
1B	Initial Leader Attachment Test (23.4.1.2)		X
1C	Swept Channel Attachment Test (23.4.1.3)	X	
2A	Swept Channel Attachment Test (23.4.1.3)	X	
2B	Swept Channel Attachment Test (23.4.1.3)	X	
3N	Swept Channel Attachment Test (23.4.1.3)	X	

23.4.1.1 High Voltage Test Waveforms

High voltage strike attachment tests are conducted using one or more of the following waveforms:

Voltage Waveform A

Voltage Waveform A is a voltage rising at the rate of 1000 kV/ μ s $\pm$ 50 percent. See Figure 23–2. The rate of rise shall be measured from 30% to 90% of the peak voltage.

Voltage Waveform D

Voltage Waveform D is a voltage rising to peak in between 50 μ s and 250 μ s with a time to 50% of peak of approximately 2000 μ s. See Figure 23–3.

23.4.1.2 Initial Leader Attachment Test

23.4.1.2.1 Test Purpose

This test is applicable to equipment designated with the High Voltage Strike Attachment Test Categories 1A and 1B. The test is used to identify likely lightning attachment locations on the equipment and, in instances where the equipment has a dielectric covering, determine breakdown paths across or through the dielectric covering.

23.4.1.2.2 Test Object

The test object should be full-scale production line hardware or a representative prototype. The test article shall be defined in the test plan.

23.4.1.2.3 Test Fixture

The test object should be installed in a test fixture that represents the actual or intended installation. The test fixture shall be defined in the test plan.

23.4.1.2.4 Test Setup

The test object and test fixture should be mounted in accordance with the test plan onto a conducting ground plane as indicated in Figure 23–4. All conducting parts of the test object normally bonded to the airframe should be bonded to the ground plane which is connected to one terminal of the high voltage generator. The other terminal of the generator shall be connected to a large plate electrode as shown in Figure 23–4. The ground plane and the electrode may need to be of sufficient size with rounded edges (electrically stress relieved). They may be either square or circular in plan view. The test arrangement is intended to result in initiation of electrical activity, such as corona and streamering, at the test object and not at the electrode.

The following steps shall be followed to setup the initial leader attachment test:

- a. Mount the test object to the test fixture. Ensure that electrical bonding of the test object to the test fixture represents the actual or intended installation.
- b. Mount the test object and test fixture to the ground plane.
- c. Electrically connect all conductive hardware on or within the test object that is normally grounded to the airframe to the ground plane as defined in the test plan.
- d. Electrically connect the output of the high voltage generator to the electrode.
- e. Electrically connect the high voltage generator return to the ground plane.
- f. Be sure that the elevated connections between the high voltage generator and the test object are farther away from the ground plane than the test object.
- g. Note that whereas it is necessary for all electrical connections normally

present between the test object and the aircraft to also be included in the test setup, it is not necessary that any specified electrical bonding resistances be met for these high voltage strike attachment tests. Electrical continuity is important, but connections via low resistance bonds are not.

- h. Set up sensing and recording equipment. This includes a high voltage divider, a recording oscilloscope and cameras to photograph the flashovers. Additional instrumentation, to measure discharge current and to photograph streamering within or behind the test object may also be included.

23.4.1.2.5 Test Waveforms

Voltage Waveform D as defined in Figure 23–3 shall be applied. If the high voltage generator discharge current exceeds the range of typical leader current of up to a few thousand amperes it may produce unrealistic effects which are beyond the scope of this test.

23.4.1.2.6 Measurements and Data Recording

The following measurements and data shall be recorded for the initial leader attachment test:

- Photographs and description of each test setup.
- Waveform plots of the test voltage and current waveforms.
- Photographic records of all high voltage discharges. These should have complete coverage of the tested surface. One camera should enable immediate preliminary analysis of the test shot to be made so that any punctures are identified immediately and before additional testing.
- Photograph of each electrode configuration.
- Photographs of puncture locations or other significant effects.
- Records of laboratory environmental data (such as temperature, pressure and humidity), dates of testing, personnel performing and witnessing the tests, and test location.
- Record of any deviations from the test procedure.
- Records of the results of each discharge showing polarity, voltage amplitude, and waveform.

23.4.1.2.7 Test Procedure

The following procedures shall be followed to conduct the initial leader attachment test:

- a. Measure laboratory environmental conditions.
- b. Review and implement safety procedures. Some areas of concern are as follows:
 - Test areas must be safe and clear of personnel prior to charging of test equipment.
 - Capacitor banks must be shorted out after tests and prior to re-entry of personnel into the test area.
 - Eye and ear protection must be appropriate.
- c. Calibrate the high voltage generator and instrumentation as follows:
 1. Carefully inspect the test object for any blemishes that might later be confused with effects of the tests, and identify them.
 2. Drape the test object with a metal foil and connect the foil to the ground.
 3. Select the initial polarity and initiate a test to the foil, while measuring the applied voltage. It is advisable that the initial polarity of the test object be positive (+).
 4. If the waveform is not per the requirements, adjust the generator parameters or electrode spacing as necessary to obtain the specified waveform.
 5. Repeat calibration steps as necessary to obtain the required conditions.
 6. Remove the foil from the test object.
- d. Clean test object with appropriate technique to remove dust, debris, and other contaminants which could affect test results.
- e. Apply a discharge to the test object, while measuring the applied voltage and taking photographic evidence of the path of the flashover. Ensure that the discharge occurs on the rising wave front before the crest of the voltage waveform. Three conditions apply for a valid test:

- The external electrode should be at least 1 m from the closest conductive element (inside or outside of the test object).
 - Connection of the streamers should occur in the air away from the test object (this can be confirmed by photographs of the flashovers).
 - The connecting leader from the external electrode must not originate from the edge of the electrode.
- f. Remove charge on test object with a grounding stick.
- g. Inspect the test object and document the results. A Tesla coil is useful for determining the location of small punctures that might be difficult to see with the naked eye. If puncture has occurred, perform an assessment to determine if the test object **COMPLIES WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS**. If it is deemed to not meet the equipment performance standards, then the test sequence may need to be terminated.
- h. Repeat steps (e) through (g) for a minimum of two high voltage discharges to the test object.
- NOTE: Since the dielectric properties of the test object may progressively degrade, the total discharges should be limited to two (2) at any particular combination of high voltage electrode and test object positions.
- i. Switch the polarity of the high voltage generator.
- j. Repeat steps (e) through (h).
- k. Reposition the high voltage electrode and test object, as required by the test plan.
- l. Repeat steps (e) through (k), as required by the test plan.

23.4.1.2.8 Data Interpretation

The test object should undergo a thorough post test evaluation. **DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS**.

23.4.1.3 Swept Channel Attachment Test

23.4.1.3.1 Test Purpose

This test is applicable to equipment designated with the High Voltage Strike Attachment Test Categories 1C, 2A, 2B, or 3N. The test is used to identify likely lightning attachment locations on the test object and, in instances where the test object has a dielectric covering, determine breakdown paths across or through the dielectric covering.

23.4.1.3.2 Test Object

The test object should be full-scale production line hardware or a representative prototype. The test article shall be defined in the test plan.

23.4.1.3.3 Test Fixture

The test object should be installed in a test fixture that represents the actual or intended installation. The test fixture shall be defined in the test plan.

23.4.1.3.4 Test Setup

An overview of a typical test arrangement showing the test object and typical test electrode position is illustrated in Figure 23–5. Large test objects, of dimensions on the order of 0.25 m or more, usually require tests from several electrode positions, as illustrated on Figure 23–6.

The following steps shall be followed to setup the swept channel attachment test:

- a. Mount the test object to the test fixture. Ensure that electrical bonding of the test object to the test fixture represents the actual installation.
- b. Mount the test object and test fixture to the ground plane.
- c. Electrically connect all conductive hardware on or within the test object that is normally grounded to the airframe to the ground plane as defined in the test plan.
- d. Connect the output terminal of the high voltage generator to the high voltage electrode. The electrode shall be per Figure 23–7.
- e. Set up sensing and recording equipment. This includes a high voltage divider, a recording oscilloscope and cameras to photograph the

flashovers. Additional instrumentation, to measure discharge current and to photograph streamering within or behind the test object may also be included.

23.4.1.3.5 Test Waveforms

Voltage Waveform A as defined in Figure 23–2 should be applied.

23.4.1.3.6 Measurements and Data Recording

The following measurements and data shall be recorded for the swept channel attachment test:

- Photographs and description of each test setup and electrode position.
- Photographic records of all tests. Cameras should provide 360 degree coverage of the test object. One camera should enable immediate preliminary analysis of the test shot to be made so that any punctures are identified immediately.
- Photographs of puncture locations or other significant effects.
- Record laboratory environmental data (such as temperature, pressure and humidity), dates of testing, personnel performing and witnessing the tests, and test location.
- Records of any deviations from the test procedure.
- Records of the results of each test showing voltage polarity, amplitude, and waveform.

23.4.1.3.7 Test Procedure

The following procedures shall be followed to conduct the swept channel attachment test:

- a. Record laboratory environmental conditions.
- b. Review and implement safety procedures. Some areas of concern are as follows.
 - Test areas must be safe and clear of personnel prior to charging of test equipment.

-
- Capacitor banks must be shorted out after test and prior to re-entry of personnel into the test area.
 - Eye and ear protection may be appropriate.
- c. Carefully inspect the test object for any blemishes that might later be confused with effects of the tests, and identify them.
- d. Calibrate the generator and instrumentation as follows:
1. Determine the desired test voltage based on a 140kV/m multiplied by the sweep distance. The sweep distance(s) shall be defined in the test plan (ref. Figure 23-5 and Figure 23-6). If the sweep distance is 0.5 m or less then the desired test voltage shall be 70 kV. The high voltage generator shall be configured to produce Voltage Waveform A.
 2. Set up the sphere gap (g), as shown in Figure 23-5, and set the sphere gap to spark over at a voltage that is 120 – 130 % of the desired test voltage. Operate the high voltage generator such that a flashover occurs at the sphere gap. The sphere gap sparkover should occur on the wavefront of Waveform A. Record the breakdown voltage for the sphere gap. If necessary, adjust the spacing of the sphere gap such that the sphere gap breaks down at 120 – 130 % of desired test voltage and repeat the sphere gap breakdown voltage demonstration. If the required waveform is not correct, adjust the generator parameters or electrode spacing as necessary to obtain the specified waveform.
 3. Connect the output terminal of the high voltage generator to the high voltage test electrode. The electrode shall be per Figure 23-7.
 4. Install the test object underneath the test electrode such that the electrode is over one of the test locations. All test electrode locations over the test object shall be defined in the test plan. Ground the test object to the high voltage generator return. Place a sheet of metal foil overtop of the test object and ground the foil to the high voltage generator return. The electrode should be placed no more than 50 mm away from the surface (d) of the test object.
 5. Operate the high voltage generator. Record the breakdown voltage for the test electrode. For desired test voltages below 140 kV, the spacing (d) may need to be reduced such that the electrode breaks down at the desired test voltage (-0/+10%). Repeat the electrode breakdown voltage demonstration as needed. The maximum test electrode spacing shall be 50 mm.

6. Remove the metal foil from the test object.
- e. Clean test object with appropriate technique to remove dust, debris and other contaminants which could affect test results.
- f. Apply test voltage to the electrode, while measuring the applied voltage and taking photographs of any flashovers that occur.

Note: If no flashover occurs to the test object the test has been successfully applied. This is an indication that insulating surfaces of the test object can successfully withstand the lightning channel voltage.

- g. Inspect the test object and document the results. Mark and photograph any punctures or other effects on the test object. If puncture has occurred, perform an assessment to determine if the test object **COMPLIES WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.** If it is deemed to not meet the equipment performance standards, then the test sequence may need to be terminated.
- h. Repeat steps (e) through (g) for a minimum of two high voltage discharges.

NOTE: Since the dielectric properties of the test object may progressively degrade, the total discharges should be limited to two (2) at any particular combination of high voltage electrode and test object positions.

- i. Switch the polarity of the high voltage generator.
- j. Repeat steps (d) through (h).
- k. Reposition the high voltage electrode and test object, as required by the test plan.
- l. Repeat steps (d) through (k) as required by the test plan.

23.4.1.3.8 Data Interpretation

The test objects should undergo a thorough post test evaluation. **DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.**

23.4.2 High Current Physical Damage Testing

23.4.2.1 High Current Test Waveforms

The current components applicable to each category shall be as shown in Table 23-2.

Table 23-2 – High Current Components

High Current Physical Damage Test Category	Test Type	High Current Waveforms						
		A	A _h	A/5	B	C*	C	D
1A	Arc Entry (23.4.2.2)	X			X	X		
1B	Arc Entry (23.4.2.2)	X			X		X	X
1C	Arc Entry (23.4.2.2)		X		X	X		
2A	Arc Entry (23.4.2.2)				X	X		X ¹
2B	Arc Entry (23.4.2.2)				X		X	X ¹
3N	Arc Entry (23.4.2.2)			X	X	X		

Note 1: Component D to be applied first.

For verification purposes, the natural lightning environment is represented by current test components A, A_h, A/5, B, C*, C and D. Each component simulates a different characteristic of the current in a lightning flash. When testing is carried out, the application of these waveforms to the appropriate category is obtained from Table 23-2. They shall be applied individually or as a composite of two or more components together in one test.

Component A - First Return Stroke Current

Component A has a peak amplitude of 200 kA ± 10 percent and an action integral of $2 \times 10^6 \text{ A}^2\text{s} \pm 20$ percent with a total time duration to 1% of peak value not exceeding 500 μs . The testing current waveform may be unidirectional or oscillatory. The rise time from 10 to 90 percent of peak current shall not exceed 50 μs .

Component A_h - Transition Zone Current

Component A_h has a peak amplitude of 150 kA ± 10 percent and an action integral of $0.8 \times 10^6 \text{ A}^2\text{s} \pm 20$ percent with a total time duration to 1% of peak value not exceeding 500 μs . The testing current waveform may be unidirectional or oscillatory. The rise time from 10 to 90 percent of peak current shall not exceed 50 μs .

Component A/5 – Zone 3 Arc Entry Current

Component A/5 has a peak amplitude of 40 kA ± 10 percent and an action integral of $0.08 \times 10^6 \text{ A}^2\text{s} \pm 20$ percent with a total time duration to 1% of peak value not exceeding 500 μs . The testing current waveform may be unidirectional or oscillatory. The rise time from 10 to 90 percent of peak current shall not exceed 50 μs .

Component B - Intermediate Current

Component B has an average amplitude of 2 kA ± 20 percent and charge transfer of 10 coulombs ± 10 percent in five milliseconds ± 10 percent. The waveform shall be unidirectional and may be rectangular, exponential or linearly decaying.

Component C - Continuing Current

Component C transfers a charge of 200 coulombs ± 20 percent in a time of between 0.25 s and 1.0 s. The waveform shall be unidirectional, may be rectangular, exponent or linearly decaying, and its average amplitude shall be between 200 and 800A.

Component C*- Continuing current for swept attachment zones with short hang-on

Component C* transfers a charge of 18 coulombs ± 20 percent in a time of 45 ms (+/- 20%). The waveform shall be unidirectional, may be rectangular, exponentially or linearly decaying, and shall have an average current amplitude not less than 400A.

Component D - Re-strike Current

Component D has a peak amplitude of 100 kA ± 10 percent and an action integral of $0.25 \times 10^6 \text{ A}^2\text{s} \pm 20$ percent. This component may be either unidirectional or oscillatory with a total time duration to 1% of peak value not exceeding 500 μs . The time from 10 to 90 percent of peak current shall not exceed 25 μs .

23.4.2.2 Arc Entry Test

23.4.2.2.1 Test Purpose

This test is applicable to equipment designated with the High Current Physical Damage Test Categories 1A, 1B, 1C, 2A, 2B, and 3N. The test is used to evaluate damage to equipment that may be exposed to the direct injection of lightning current. For fuel components, the additional procedures of 23.4.3.2 shall be used for ignition source detection. Equipment with electrical circuits which may have voltage transients injected into them during a direct lightning attachment shall use the additional procedures of 23.4.3.3 to measure these transients.

23.4.2.2.2 Test Object

The test object should be full-scale production line hardware or a representative prototype. The test article shall be defined in the test plan.

23.4.2.2.3 Test Fixture

The test object shall be mounted in a test fixture that represents the actual or intended installation. The test fixture shall be defined in the test plan.

23.4.2.2.4 Test Setup

The following steps shall be followed to setup the arc entry test:

- a. Mount the test object in the test fixture.
- b. Connect the generator return to the test fixture as defined in the test plan. The lightning currents should be conducted away from the test object in a manner representative of when the aircraft is struck by lightning.
- c. Orient a test electrode such that the exposed conductive portion of the electrode is 50 mm or greater above the area of the test object that is to be evaluated. For most arc entry tests the electrode should be the "jet diverting" type, as shown in Figure 23-8. A jet diverting electrode has an insulating material covering all surfaces that face the test object, thus forcing the arc to originate from a surface which faces away from the test object. The distance between the test object and the nearest non-conductive portion of the jet diverting electrode shall be at least 25 mm. If blast or shock wave effects are not of concern, a rod electrode with rounded tip and a diameter of 50 mm or greater can be used. The electrode shall be capable of conducting the required test currents.
- d. A fine metallic wire, not exceeding 0.1 mm diameter, may be used, if desired, to direct the arc to a specific point of interest on the test object. This approach is helpful for generators that use lower voltages.
- e. Set up sensing and recording equipment.

23.4.2.2.5 Test Waveforms

A subset of current waveforms A, A_h, A/5, B, C, C* and D are used for this test, depending upon the test category (see Table 23-2).

23.4.2.2.6 Measurements and Data Recording

The following measurements and data are required for the arc entry test:

- Photographs and description of the test setup.
- Photographs of the test object both before and after each discharge.
- Photographs and description of damage to the test object.
- Records of laboratory environmental data (such as temperature, pressure and humidity), dates of testing, personnel performing and witnessing the tests, and test location.
- Record of any deviations from the test procedure.
- Records of the results of each discharge showing polarity, currents amplitudes, waveforms, action integrals and charge transfers at applicable test points.
- Records of voltage and/or current transients on electrical conductors associated with the test object (as required by the test plan).

23.4.2.2.7 Test Procedure

The following procedures shall be followed to conduct the arc entry test:

- a. Record laboratory environmental conditions.
- b. Review and implement laboratory safety procedures.
- c. Verify the high current generator, discharge circuit and sensing and recording equipment as follows:
 1. Insert a dummy test object in the test fixture beneath the electrode or place a conductive bar over the actual test object such that the waveform checkout discharge cannot damage the test object. The dummy test object or conductive bar should have approximately the same dimensions and conductivity as the test object.
 2. Connect the test fixture or bar to the generator return.
 3. Initiate a discharge to the dummy test object/bar, while measuring the applied current waveform(s).
 4. If the current level or waveform(s) are not correct, adjust the generator parameters.
 5. Repeat steps 3 through 4 as necessary to obtain the required

current levels and waveform(s).

6. Remove the dummy test object or bar. Install the test object in the test fixture.
- d. Initiate a discharge to the test object.
- e. Inspect the test object and document the results.
- f. If required, orient the electrode in a new position and repeat steps (d) through (e).

23.4.2.2.8 Data Interpretation

The test object should undergo a thorough post test evaluation. **DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.**

23.4.3 Additional Test Requirements

23.4.3.1 Externally Mounted Fuel Equipment

Externally mounted fuel equipment such as filler caps, and magnetic fluid level indicators, requires additional detection techniques to ensure they do not create any ignition sources with an energy greater than or equal to 200 microjoules. The following methods are applicable to all high current physical damage test categories.

23.4.3.2 Methods for Detection of Ignition Sources

Ignition sources that have an energy greater than or equal to 200 microjoules can be detected by photographic methods or by a sensitive ignitable fuel mixture. High current physical damage tests that require detection of ignition sources shall be performed per the procedures detailed in section 23.4.2.2 with the addition of one or both of the ignition source detection methods detailed below.

23.4.3.2.1 Photographic method

23.4.3.2.1.1 Test Purpose

This method uses photography to detect ignition sources of electrical sparks (voltage sparks) or thermal sparks (electrical arcs) during high current testing of

fuel system components. This method should only be used when all angles of a test object can be observed. If all angles cannot be viewed or there are obstructions from complex builds then a combination of photographic and ignitable mixture tests should be used. The photographic method used must be capable of detecting 200 microjoules electrical sparks. Thermal sparks which present an equivalent hazard usually give off more light and are easier to detect than a 200 microjoules voltage spark.

The photographic method has several advantages including ease of test apparatus set-up and a permanent record of the test that can be used to identify the origin of the ignition sources and thus help with failure analysis.

23.4.3.2.1.2 Test Equipment

a. Camera and Film

Both 35mm and Polaroid films can be used in this method. The combination of camera and film should be shown to have adequate sensitivity to identify a 200 μ J voltage spark. Polaroid black and white 3000ASA speed film (617) exposed through an F4.7 lens (without filters) no more than 1.5 meters from potential ignition sources (including mirror reflection distance) meets this requirement. 35mm film shall be shown to have adequate sensitivity to the 200 microjoules voltage spark yet with fine enough granularity to allow definition of the spark for the lens type being used. The development time-temperature combination recommended by the manufacturer shall be followed. Outdated film shall not be used.

b. Mirrors

It may be necessary to view several angles of the test object during the testing. This may be accomplished by using front surface mirrors with care given to minimize reflective loss which could alter the sensitivity of the cameras. Typically, one surface reflection is acceptable. If one or more mirrors are used, the total reflection loss should be less than 15 percent.

c. Light-Tight Test Chamber

The photographic technique requires a light-tight test chamber to allow for the camera apertures to be open during the lightning test current discharge. Reference LED's or a small light source should be available to help identify ignition source locations and verify the camera shutters were open during test.

23.4.3.2.1.3 Test Procedure

- a. Setup the cameras. Ensure all cameras are in focus and there is adequate visibility of all potential light sources.
- b. Pre-test photo set up. Take photographs of the illuminated test object to help identify locations of sparking seen during the test.
- c. Verify the setup is sufficiently light-tight and that any sparking at test rig connections will not confuse detection of hazardous sparking on the test object.
- d. Open the camera shutter(s) and then follow the high current test set-up and discharge per (Section 23.4.2.2).
- e. Prior to closing the camera shutter(s), illuminate a small light source within the test box to verify that the shutter(s) were open during test. Close the shutter(s).
- f. Inspect the film to determine the presence of ignition sources. For Polaroid film the negative print is the most sensitive and should be studied first. Any light should be an indication of a possible fuel ignition source. The use of two or three cameras will help eliminate possible film defects that may otherwise be confused as light sources.

23.4.3.2.1.4 Data Requirements

If the photographic method is used the additional data recording requirements are:

- Camera settings, film types, and film manufacturers used during test.
- Measured distance from cameras to test object.
- Measured mirror reflection loss.
- If a photographic method falls outside the guidelines given above, the sensitivity of the method to 200 microjoules voltage sparks should be demonstrated with a 200 microjoules controlled energy ignition voltage spark source to calibrate the film speed, aperture setting, reflective surfaces and distance from the camera film plane.

23.4.3.2.2 Ignitable Mixture (Flammable Gas) Test Method

23.4.3.2.2.1 Test Purpose

WARNING: Testing with combustible gas mixtures is dangerous, suitable precautions shall be taken.

This method can be an alternate to or in combination with the photographic method for detection of potential ignition sources. Ignitable mixture is the preferred method for cases where transient hot spots can occur. This method is to be used where all the possible ignition sources within a test configuration cannot be satisfactorily viewed by cameras.

A hydrogen/oxygen/argon mixture (5% Hydrogen, 12% Oxygen, and 83% Argon) is the preferred gas for the ignitable mixture testing. This mixture has a demonstrated greater than 90% probability of ignition when exposed to a 200 microjoule voltage spark source. In addition, this mixture provides a very low energy release during the burn, improving safety aspects of the test and reducing the pressure relief requirements of the test chamber. Hydrogen does not emit visible light during the burn allowing the simultaneous use of the photographic test method, which can improve confidence in the test results.

If an ignitable mixture is used and no ignition occurs during the test, verification of the mixture combustibility shall be obtained by ignition with a controlled energy ignition voltage spark source of no more than 200 μ J introduced into the test chamber immediately after the lightning test. If the combustible mixture is not ignited by the controlled energy ignition voltage spark source, the lightning tests shall be considered invalid and the tests repeated with a new mixture until either the lightning tests or the controlled energy ignition voltage spark source ignites the mixture.

If there is difficulty meeting the gas calibration procedure (section 23.4.3.2.2.a) requiring 9 out of 10 ignitions with a 200 microjoule voltage spark source, the controlled energy voltage spark source should be evaluated per the procedure to establish confidence in the 200 microjoules noting that there can be sensitivity to temperature, humidity, gap spacing, and electrode cleanliness.

If there is confidence in the controlled energy spark source, the hydrogen concentration of the hydrogen/oxygen/argon mixture may be increased by 0.5% increments (maintaining the 1.2 stoichiometric concentration) until the 9 out of 10 requirement is met. The hydrogen concentration shall not exceed 7%.

	Hydrogen	oxygen	argon
Initial mixture	5%	12%	83%

0.5% hydrogen increase	5.5%	13.2%	81.3%
1.0% hydrogen increase	6.0%	14.4%	79.6%
1.5% hydrogen increase	6.5%	15.6%	77.9%
2.0% hydrogen increase	7.0%	16.8%	76.2%

CAUTION: Use the minimum hydrogen concentration mixture necessary to achieve the gas calibration requirement of 9 out of 10 ignitions with a 200microjoule voltage spark source. At the 5% hydrogen concentration the target Minimum Ignition Energy (MIE) is 200 microjoules. Increasing the hydrogen concentration beyond this level could result in a conservative test sensitivity.

23.4.3.2.2.2 Test Equipment

a. Test Box and Flow Control System

The test box should have as small a volume as practical to minimize the volume of gas mixture to minimize the energy released when ignition occurs. The test box shall also incorporate a blow-out hole/feature to prevent pressure build-up and to verify the ignition of the mixture. Displacing the test box volume five times with gas mixture flow allows confidence that the necessary mixture is present in the test box volume. A flow control system is necessary to control the mixture of gases introduced into the test chamber. Typically, compressed gas flow is controlled by mass control flow meters to set the desired flow rates into the test chamber. An example flow rate calculation is as follows:

For 5% Hydrogen, 12% Oxygen, and 83% Argon

Test Box Volume = One cubic foot = 28.3 liters

Introducing 5 volumes in 5 minutes requires a flow of 28.3 standard liters per minute (SLPM). The rates would be: Hydrogen 1.4 SLPM, Oxygen 3.4 SLPM, Argon 23.5 SLPM.

b. Controlled Energy Ignition Voltage Spark Source

A controlled energy ignition voltage spark source is necessary to verify and quantify the ignition characteristics of the gas mixture both before and after the lightning test discharge. This controlled source shall produce a voltage spark between two 3.2 mm diameter aluminum electrodes, spaced 1.5 - 2.0 mm apart. The voltage spark energy shall be no larger than

200 microjoules.

One method to produce the voltage spark is to discharge a small capacitor across the gap. The energy discharged across the gap can be calculated based on the value of the capacitor (C) and the charge voltage (V). This assumes that all of the potential energy stored in the system ($\frac{1}{2}CV^2$) will be dissipated in the voltage spark that spans the volume between the two electrodes. To insure that this assumption is valid, short heavy leads and solid connections should be used between the capacitor and voltage spark gap. As an example, in air, a 2 mm gap will spark at 7.95 kV +/- 5%. At this voltage about 6pF of capacitance is required to store the 200 microjoules of energy needed to validate the gas mixture ignitibility. The actual breakdown voltage in the hydrogen-oxygen-argon mixture is lower than the breakdown in air. Thus the capacitance will need to be higher to ensure a 200 microjoules spark.

Figure 23–9 shows a schematic of an example controlled energy ignition source. To prevent multiple discharges, the charging time constant needs to be on the order of seconds requiring a resistance of approximately 150 GΩ. Resistances of this magnitude require that the support structure be of very high resistance or the system will not charge to the breakdown level. The spark gap voltage is measured with an electrostatic voltmeter. The 50 MΩ isolation resistors between the gap and ground insure that only the energy stored on the vacuum capacitor is delivered to the gap. Additionally, a corona source is used to ensure a consistent breakdown voltage across the gap.

23.4.3.2.2.3 Test Procedure

a. Gas Mixture Calibration Procedure

Prior to conducting lightning tests the gas mixture/test volume probability of ignition at the minimum energy voltage spark level of 200 microjoules must be verified and documented. This information is necessary to determine the level of confidence in the lightning test results. This calibration test is performed before mounting the test specimen in the chamber.

1. Set gas flow rates.
2. Visually inspect the electrode tips. Clean and polish electrode tips and set/verify gap spacing as required. This need only be done once per test session.
3. Seal the blow out hole of test box.

-
4. Adjust controlled energy ignition voltage spark source to 200 microjoules.
 5. Begin calibration test sequence by filling chamber to displace five test volumes
 6. Discharge controlled energy ignition voltage spark source and record breakdown voltage, ignition (yes/no), time of test, and calculated energy injected.
 7. If no ignition occurs, wait two minutes and repeat spark. Ignite with high-energy spark source after five attempts.
 8. Repeat the test steps 5 through 7 at least nine times and record number of ignitions to verify the gas mixture ignites at least nine times out of ten successive tests. Check the gap spacing and polish/clean the electrode tips periodically. Verify the capacitance at the beginning and end of each sequence.

b. Lightning Test Procedure

1. Set gas flow rates.
2. Seal the blow out hole of test box.
3. Adjust controlled ignition source to 200 microjoules.
4. Begin test sequence by filling test chamber to displace five test volumes.
5. Follow high current arc entry (Section 23.4.2.2) test setup and discharge test procedures.
6. If an ignition occurred during the high current discharge, **DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.**
7. If no ignition occurred due to lightning test discharge, fire the controlled energy ignition voltage spark source to verify that the mixture is flammable.
8. If the controlled energy ignition voltage spark source does not ignite mixture, wait two minutes and repeat. Ignite with a high-energy voltage spark source after five attempts with the controlled energy ignition voltage spark source. If the controlled energy ignition voltage spark source does not ignite mixture then the test is invalid.

9. Repeat steps 1 through 8 for subsequent tests. Check the gap spacing and polish/clean the electrode tips periodically. Verify the capacitance at the beginning and end of each sequence.

NOTE: If additional tests are planned on the same test article then all of these tests may be applied prior to firing the controlled energy ignition voltage spark source. If in the event that the successful ignition per steps (7) and (8) with the controlled energy ignition voltage spark source is not obtained, all of the tests applied to this article must be considered invalid. The proper mixture inside the chamber should be maintained for the full duration of the test.

23.4.3.2.2.4 Data Requirements

If an ignitable mixture test is performed the data recording requirements are:

- Types, grades, and concentrations of gases.
- Flow rate calculation.
- Probability of ignition due to controlled voltage spark source calculation (i.e. results of 10 calibration ignitions).
- Verification of energy within controlled energy ignition voltage spark source.

23.4.3.3 Measurement of Induced Voltage in External Hardware

23.4.3.3.1 Test Purpose

This test method is applicable to equipment designated with High Current Physical Damage Test Categories 1A, 1B, 1C, 2A, 2B, and 3N. This method measures the voltage appearing directly onto the electrical connector of the EUT while the equipment is exposed to lightning current. This characteristic of the equipment may be used for choosing the connector type, and for dimensioning the rating of protection devices for the internal equipment connected to this externally mounted equipment.

23.4.3.3.2 Test Object

The test object should be full-scale production line hardware or a representative prototype. The structure, wiring, and equipment installation should be electromagnetically similar to the intended production configuration. The test object should include installation provisions such as gaskets, bonding jumpers,

paint and sealants. The test object shall be defined in the test plan.

23.4.3.3.3 Test Fixture

The test object shall be mounted in a test fixture that represents the actual or intended installation. The test fixture shall be defined in the test plan.

23.4.3.3.4 Test Setup

The following steps shall be followed to setup for injected transient measurements:

- a. Mount the test object to the test fixture. The mounting of the test object in the test fixture shall be defined in the test plan. Figure 23–10 shows a simple test fixture.
- b. Set up the high current generator in accordance with test set up requirements for arc entry (Section 23.4.2.2).
- c. Set up the voltage measurement probes and recording equipment. The recording instrument(s) should have a minimum bandwidth of 30 MHz.
- d. Provide shielding for any measurement probes and recording equipment to minimize measurement noise. A suitably shielded instrument cable or optical fiber link should be used between the measurement probes and the recording equipment.

23.4.3.3.5 Measurement and Data Recording

The following measurements and data are required for the measurement of injected transients:

- Photographs and description of the test setup.
- Photographs and descriptions of instrumentation probes for electrical circuits and harness arrangement.
- Photographs of the test object both before and after each discharge.
- Photographs and description of damage to the test object.
- Records of laboratory environmental data (such as temperature, pressure and humidity), dates of testing, personnel performing and witnessing the

tests, and test location.

- Record of any deviations from the test procedure.
- Records of the results of each discharge showing polarity, currents amplitudes, waveforms, action integrals and charge transfers at applicable test points.
- Records of amplitude and waveforms of voltages.

23.4.3.3.6 Test Procedure

- a. Measure laboratory environmental conditions.
- b. Review and implement safety procedures. Some areas of concern are as follows:
 - Test areas must be safe and clear of personnel prior to charging of test equipment and capacitor banks must be shorted out prior to entry of personnel into the test area.
 - Eye and ear protection may be appropriate.
- c. Calibrate the generator and instrumentation as follows:
 1. Detach the high side of the high current generator from the test object and connect it to a conductive bar that is connected to the generator return point of the test object. The bar should have material properties that are similar to the test object.
 2. Initiate a discharge to the bar, while measuring the applied current waveform and the induced levels in the electrical circuit instrumentation.
 3. If the current level or waveform is not correct, adjust the generator parameters.
 4. If the induced noise levels in the instrumentation circuit are above those expected, modify the instrumentation setup to reduce the induced levels.
 5. Repeat steps (2) thorough (5) as necessary to obtain the required conditions.
- e. Remove the bar and reattach the generator to the test object.
- f. Initiate a discharge to the test object per Section 23.4.2.2 (Arc Entry),

while measuring the applied current waveforms and the voltage transients on the test object's electrical wires.

- g. Inspect the test object and document the results.

23.4.3.3.7 Data Interpretation

THE MEASURED VOLTAGE RESPONSES SHALL BE EVALUATED TO DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

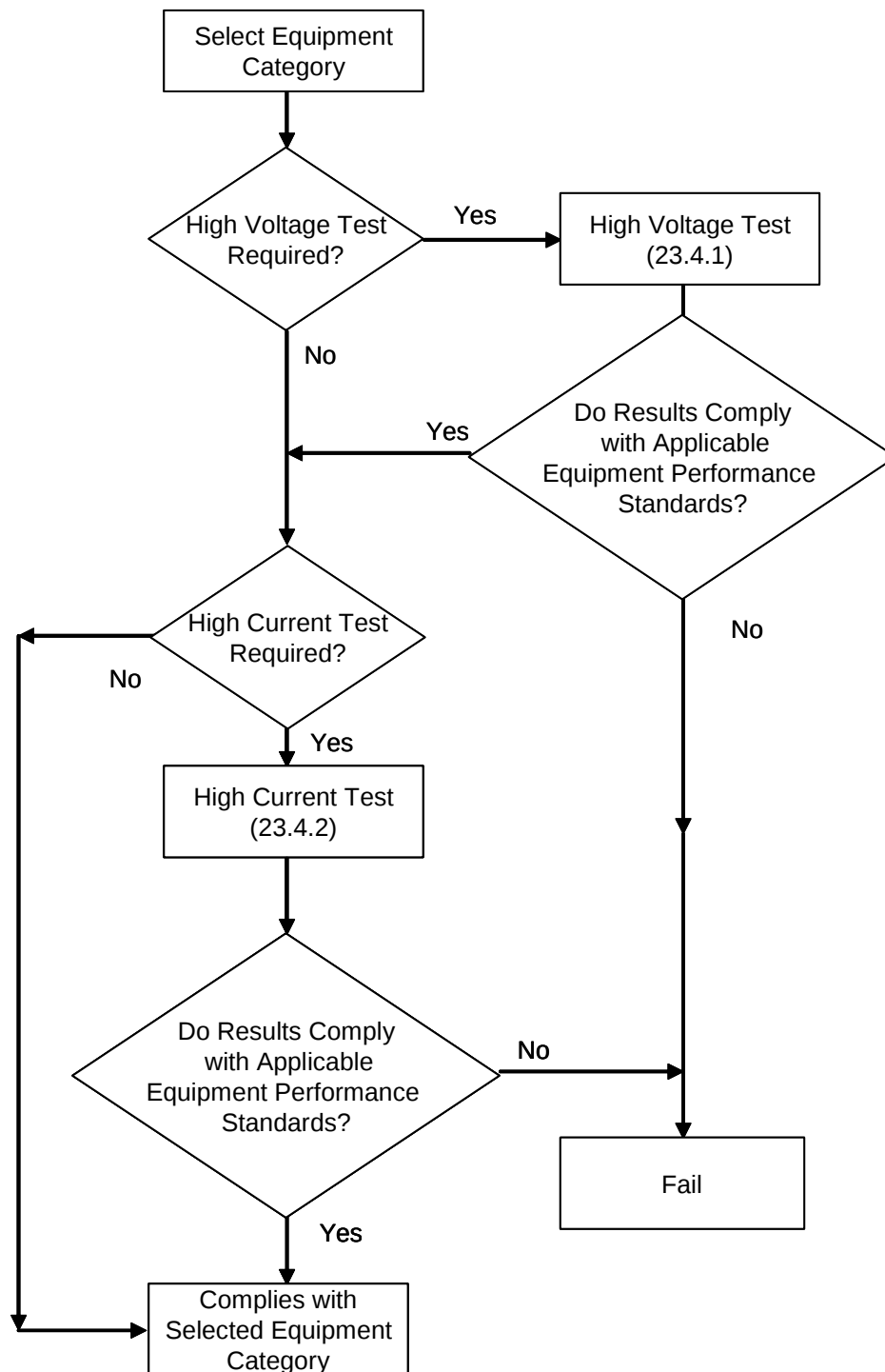
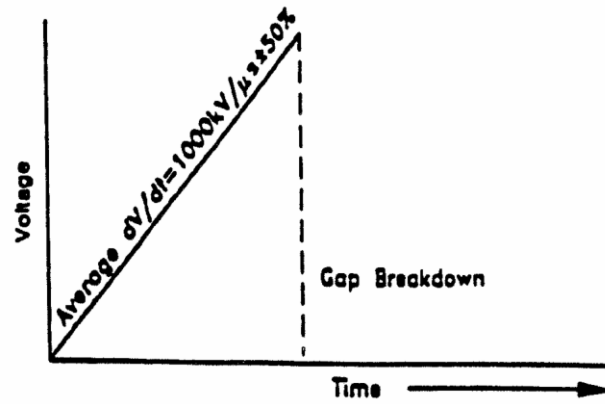


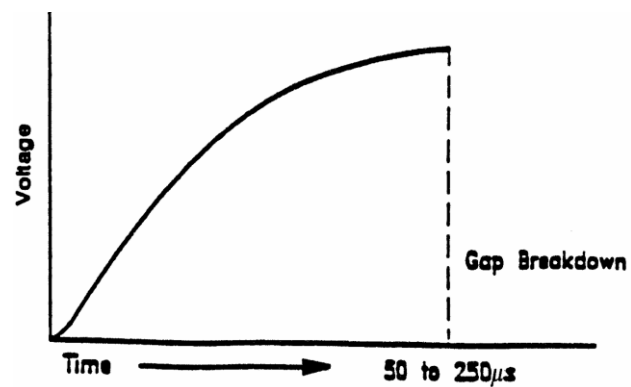
Figure 23-1 – Flow Chart for High Voltage and High Current Tests



Total Gap Length	Electrode Positive	Electrode Negative
0.5m	750kV	790kV
1.0m	1300kV	1400kV
1.5m	2250kV	2400kV

Approximate Voltage Requirements

Figure 23-2 – Voltage Waveform A



Total Gap Length	Electrode Positive	Electrode Negative
0.5m	350kV	400kV
1.0m	500kV	600kV
1.5m	600kV	700kV

Figure 23-3 – Voltage Waveform D

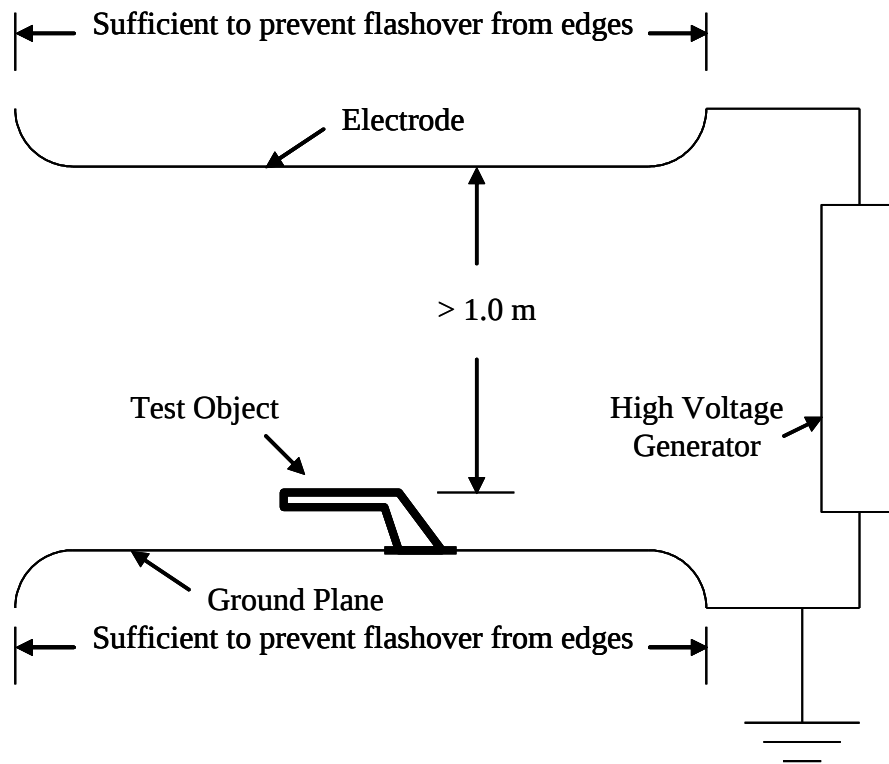


Figure 23-4 – Initial Leader Attachment Test Setup

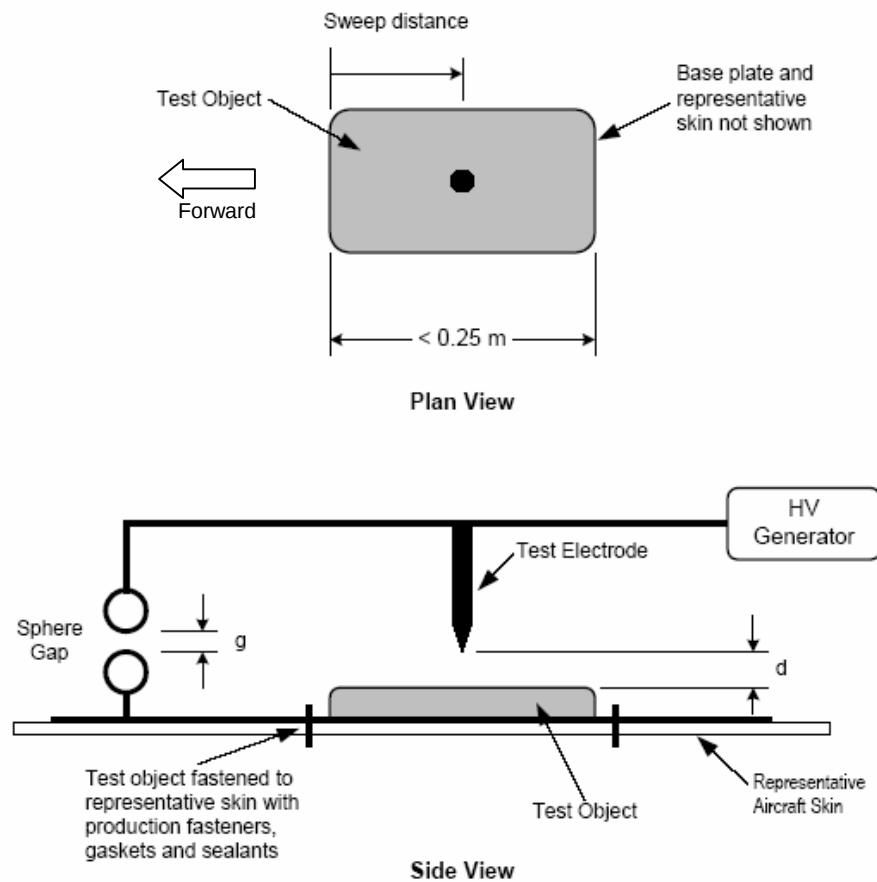


Figure 23-5 – Arrangement for Swept Channel Attachment Test of Small Test Objects

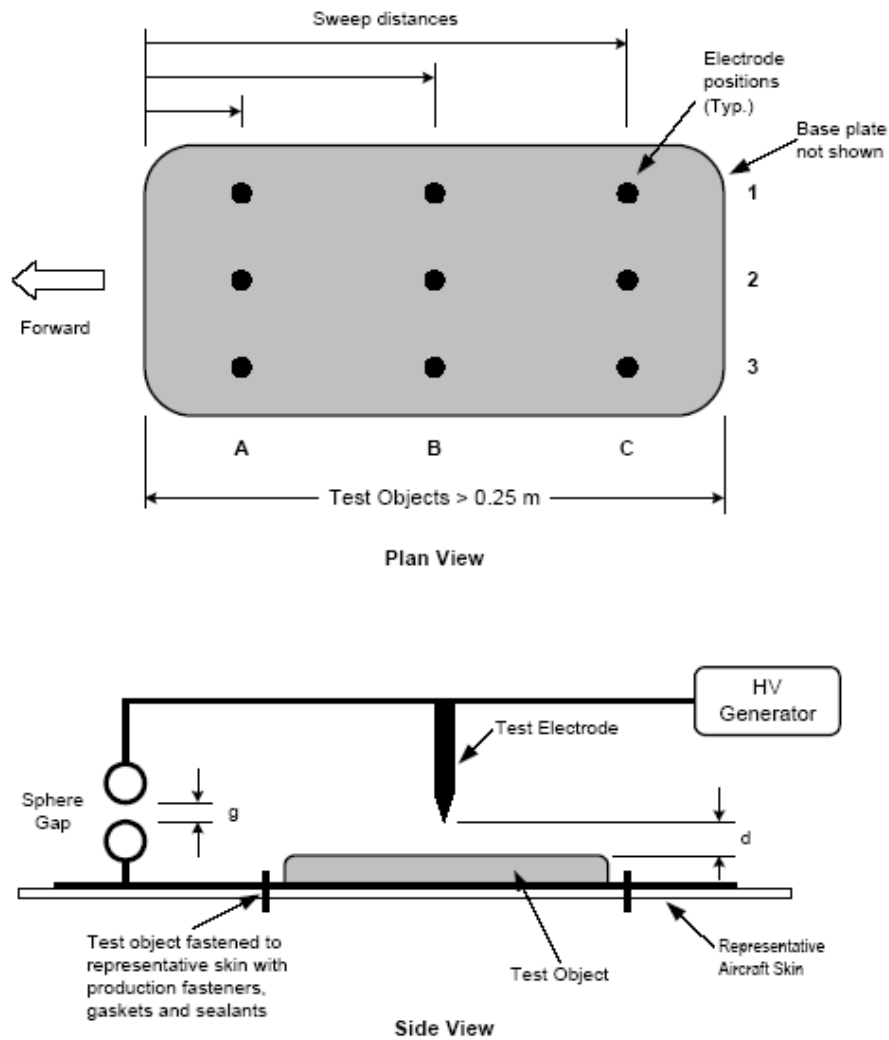


Figure 23-6 - Arrangement for Swept Channel Attachment Test of Large Test Objects

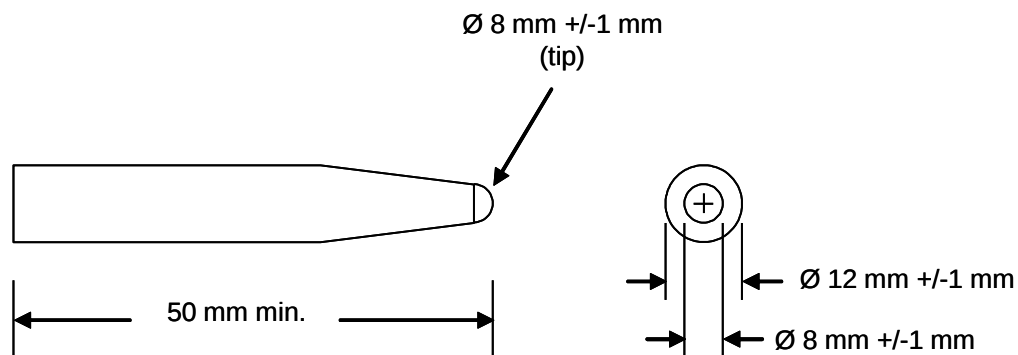


Figure 23-7 - Test Electrode for Swept Channel Attachment Test

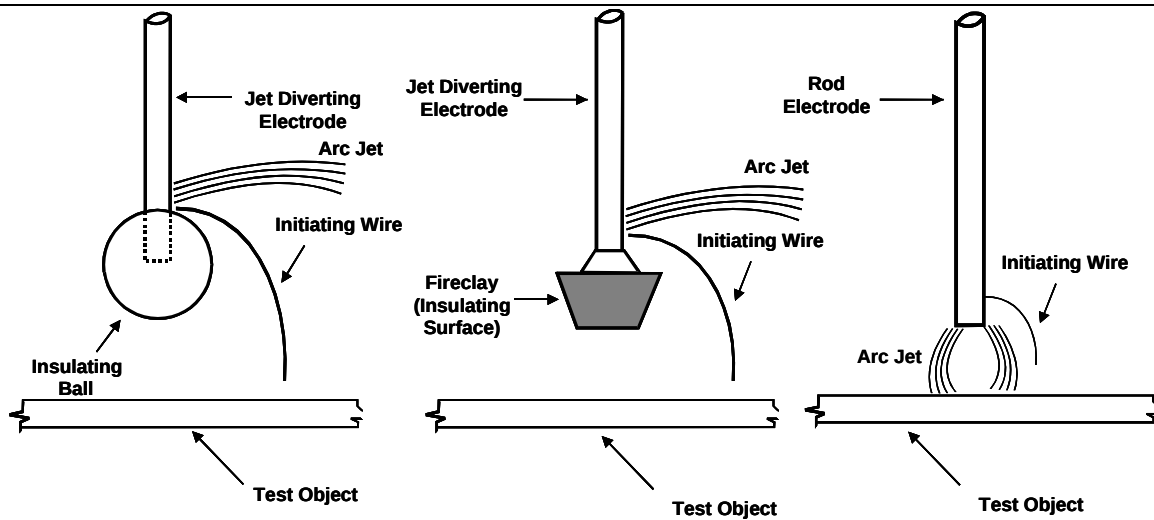


Figure 23-8 - Typical Test Electrodes

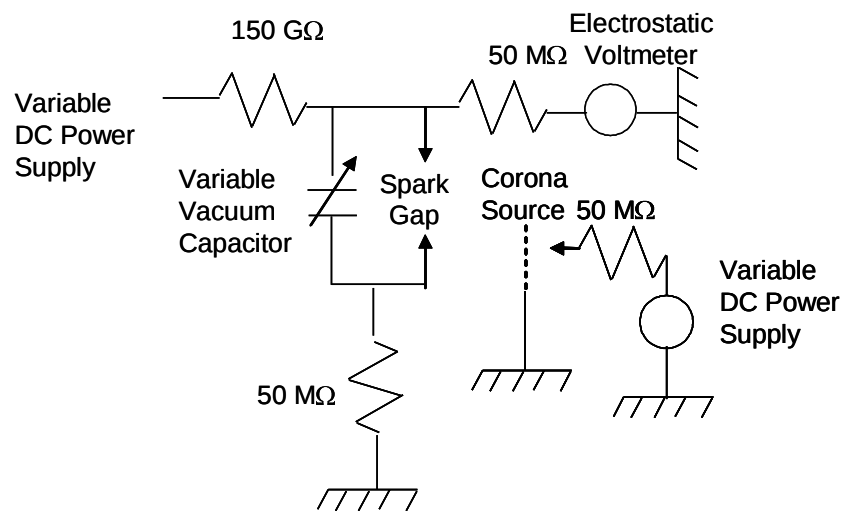


Figure 23-9 - Controlled Energy Ignition Voltage Spark Source

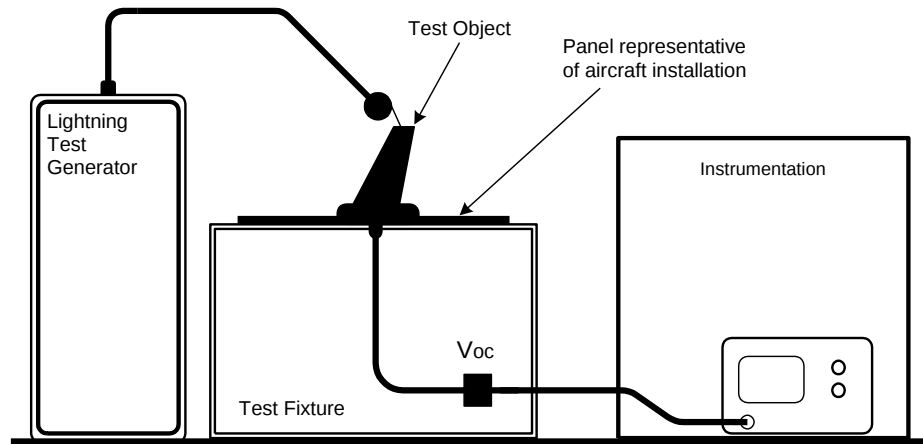


Figure 23–10 – Typical Installation for Measurements of Injected Transients

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 24

Icing

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2 and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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24.0 Icing**24.1 Purpose of the Test**

These tests determine performance characteristics for equipment that must operate when exposed to icing conditions that would be encountered under conditions of rapid changes in temperature, altitude and humidity.

24.2 General

Three icing test procedures are specified according to the category for which the equipment is designed to be used and installed in the aircraft (see Subsection 24.3).

Note: The selection of icing category depends on equipment location in (or on) the aircraft and the type of icing conditions expected. These conditions must be considered by the equipment designer in evaluating these requirements, which are determined by the end application and use of the equipment. These tests generally apply to equipment mounted on external surfaces or in non-temperature controlled areas of the aircraft where rapid changes in temperature, altitude and humidity are generally encountered.

These procedures specify test methods for evaluating the effects of various icing conditions on the performance of aircraft equipment, namely:

- a. The effects of external ice or frost adhering to it.
- b. The effects of ice caused by freezing of water condensation or by re-freezing of melted ice.
- c. The effects of ice build-up caused by direct water exposure.

24.3 Equipment Categories

The following categories cover the anticipated ice formation conditions generally encountered in aircraft.

Category A

This test is applicable to equipment mounted externally or in non-temperature-controlled areas of the aircraft, where ice or frost may form due to condensation when the equipment is cold soaked to extremely low temperatures and subsequently encounters humid air at above freezing temperatures.

Category B

This test is applicable to equipment with moving parts where such movement could be prevented or impeded by ice formation, or where forces resulting from the expansion of ice could damage structural or functional components. The ice formed in or on the equipment results from condensation, freezing, melting and/or re-freezing and may progressively accumulate water or ice inside non-sealed enclosures.

Category C

This test is applicable to items mounted externally or in non-temperature-controlled areas where there is risk of accumulating free water, which could subsequently freeze on the cold surfaces of the equipment. The test is intended to examine the effects of a representative thickness of ice on the performance of the equipment or to determine the maximum thickness that can be permitted before de-icing action is necessary. The required thickness and distribution of ice and any requirement for progressive build-up of ice shall be defined by the APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

24.4 Test Procedure

24.4.1 General

Mount the equipment under test in a manner representative of the normal installation in the aircraft. Remove all non-representative contaminants, such as oil, grease and dirt, which would effect adhesion between ice and the surfaces of the equipment under test, before beginning the appropriate tests. Operation of equipment that generates heat shall be limited to only that period of time necessary to determine compliance. The steps described in the Category A and Category B procedures are illustrated in Figure 24-1 and Figure 24-2.

24.4.2 Category A

- a. With the equipment not operating, stabilize the equipment temperature at the low ground survival temperature specified in Table 4-1 at ambient room pressure and humidity.
- b. As quickly as practical, expose the equipment to an environment of 30 degrees C with a relative humidity of at least 95 percent. Monitor the surface temperature of the equipment.
- c. Maintain the environment at 30 degrees C and a relative humidity of at least 95 percent until the surface temperature of the equipment reaches five degrees C. As quickly as practical, change the environment to the appropriate ground survival low temperature at ambient pressure and humidity.
- d. Repeat steps a. through c. for two additional cycles (total of three cycles).

- e. At the end of the third cycle, stabilize the equipment at the ground survival low temperature. Increase and maintain the chamber temperature to -10 degrees C and permit the surface temperature of the equipment to rise. When the surface temperature reaches -10 $\pm$ 5 degrees C, place the equipment into the operating state and DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: This test is designed to expose the equipment alternately to cold dry and warm moist environments. The use of separate chambers representing these two distinct environments is recommended.

24.4.3

Category B

- a. With the equipment not operating, stabilize the equipment temperature at -20 degrees C at ambient room pressure. Maintain this temperature and decrease the chamber pressure to the appropriate maximum operating altitude specified in Table 4-1. Maintain this condition for a period of at least 10 minutes.
- b. Raise the chamber temperature at a rate not exceeding three degrees C/minute while simultaneously increasing and maintaining the relative humidity in the test chamber to not less than 95 percent. Maintain this condition for a sufficient period of time to melt all frost and ice or until the surface temperature of the equipment reaches between zero to five degrees C. The chamber temperature should not be allowed to exceed 30 degrees C at any time during this step.
- c. Increase the chamber pressure to room ambient at a uniform rate in a period of 15 to 30 minutes. At the completion of the re-pressurization, reduce the relative humidity in the chamber to normal room ambient.
- d. Repeat steps a. through c. for a total of 25 cycles or as defined in the applicable equipment specification, whichever is less.

Note: If it becomes necessary to interrupt the test sequence, the interruption shall take place while the equipment is held at the low temperature condition.

- e. At the end of the last test cycle, after the equipment temperature has stabilized at -20 degrees C, DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

24.4.4

Category C

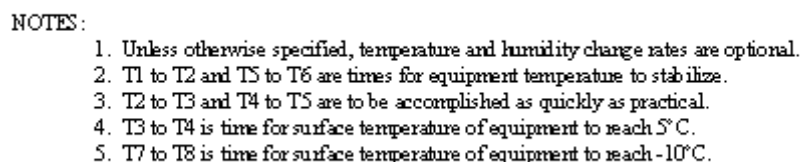
- a. With the equipment not operating, stabilize the equipment at a temperature that will permit clear, hard ice to form on the equipment when sprayed with water.

Note 1: For this test, the ice formed shall be clear and hard (glaze ice). "White" or air-pocketed ice (rime ice) is not acceptable.

Note 2: The optimum temperature is likely to be between -1 and -10°C depending on the thermal mass of the equipment and is best determined by experiment.

- b. Build up a homogeneous layer of clear hard ice to a thickness defined by the APPLICABLE EQUIPMENT PERFORMANCE STANDARD by hand spraying a fine mist of water at a temperature that is close to freezing.
- c. When the required thickness of ice has been achieved, discontinue the spraying. Place the equipment into the operating state and stabilize the equipment at a temperature of -20 degrees C. DETERMINE COMPLIANCE WITH THE APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

Note: If multiple tests with increasing thickness of ice formation are required, a series of separate tests shall be performed with each thickness level formed in a continuous operation.



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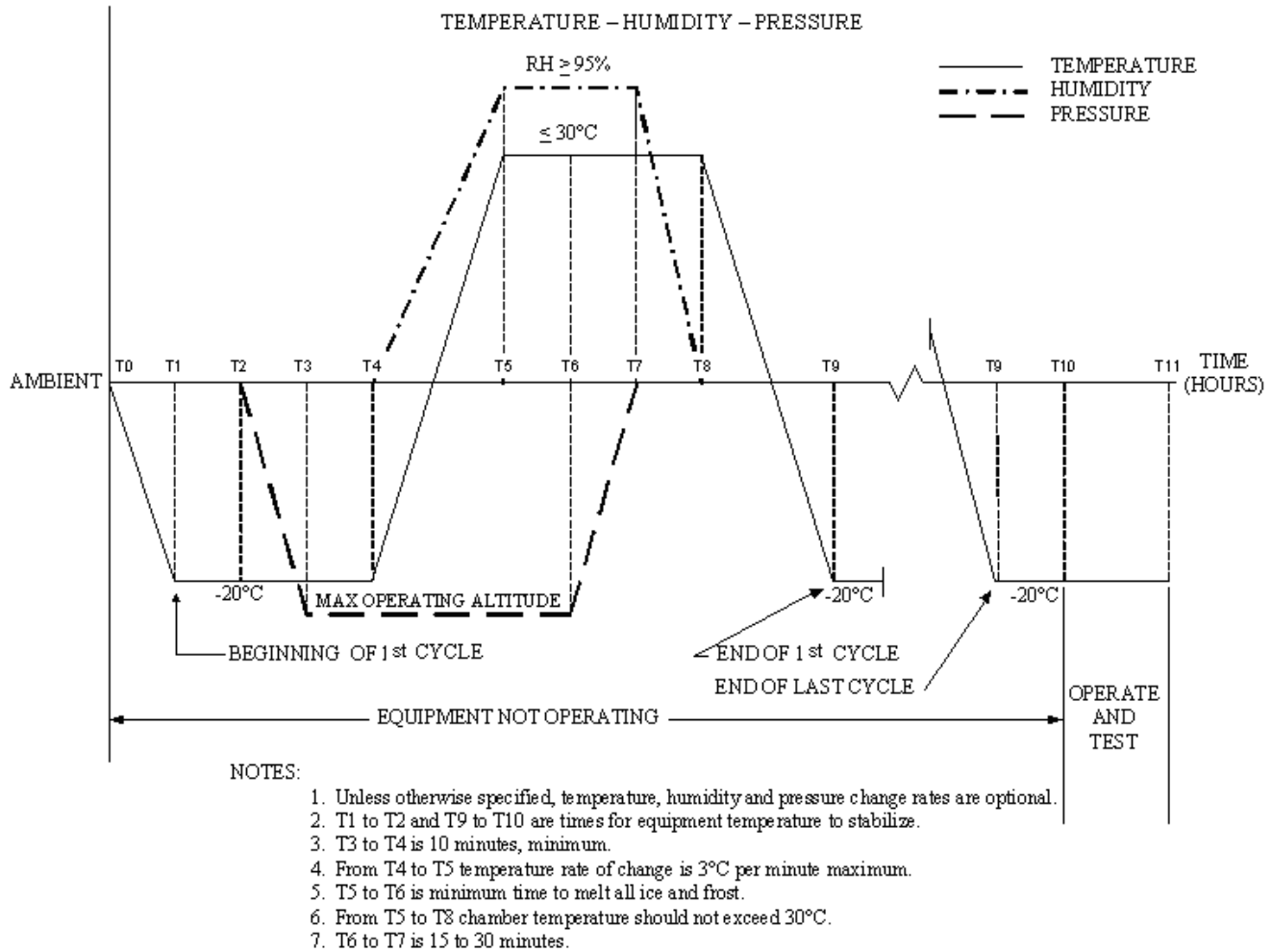


FIGURE 24-2 CATEGORY B ICING TEST

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Environmental Conditions and Test Procedures for Airborne Equipment

Section 25

Electrostatic Discharge (ESD)

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2, 3 and 20. Further, Appendix A is applicable for identifying the environmental tests performed.

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25 Electrostatic Discharge (ESD)

25.1 Scope

The Electrostatic Discharge test relates to airborne equipment which may be involved in static electricity discharges from human contact. Some factors contributing to an ESD event may be: low relative humidity, temperature, use of low conductivity (artificial fiber) carpets, vinyl seats and plastic structures which may exist in all locations within an aircraft. This test is applicable for all equipment and surfaces which are accessible during normal operation and/or maintenance of the aircraft. This test is not applicable to connector pins.

25.2 Purpose of the Test

The electrostatic discharge test is designed to determine the immunity or the ability of equipment to perform its intended function without permanent degradation of performance as a result of an air discharged electrostatic pulse.

25.3 Test Description

The immunity to electrostatic discharge shall be determined by the ability of the equipment under test (EUT) to withstand a series of electrostatic discharge pulses at a test level of 15,000 volts, directed at specific human contact locations on the EUT. The quantity of pulses shall be ten (10) in each of the selected locations and in both positive and negative voltage polarities (10 positive and 10 negative). The test configuration is depicted in [Figure 25-1](#).

25.4 Equipment Categories

Category A - Electronic equipment that is installed or operated during normal operation and/or maintenance of the aircraft.

25.5 Test Procedure

With the equipment powered and operated in the required mode the electrostatic discharge test will be performed under the following conditions:

- 25.5.1 Test Configuration** - The EUT shall be set up as shown in Section 20.3a (General Test Requirements). Connect and orient the equipment as specified by the applicable installation and interface control drawings or diagrams. Care must be taken in routing and grounding of the cabling associated with the ESD generator to minimize the potential for secondary effect of the radiated field from the cabling. This test is intended to test the primary effect which is the discharge from the ESD generator to the enclosure of the equipment under test. This includes the normal method of mounting, bonding, and grounding of the equipment.

25.5.2 ESD Generator - The ESD generator shall have a general schematic as shown in Figure 25-2, with a discharge resistor of 330 ohms ($\pm 20\%$) and an energy storage capacitor of 150 pf ($\pm 20\%$), and shall be capable of generating a pulse of 15,000 volts, in both positive and negative polarities. The ESD generator shall also have an air discharge tip as shown in Figure 25-3. The ESD generator shall be calibrated to produce a positive and negative 15,000 volt ($+10\%$, -0%) peak output pulse. The generator setting required to produce this output shall be recorded.

25.5.3 EUT Test Modes - EUT test modes shall include software (if applicable) chosen to exercise all normal modes of operation of the EUT.

Note: If monitoring equipment is required, it should be decoupled in order to reduce the possibility of erroneous failure indications.

25.5.4 Selection of Test Points - The test points to be considered shall include the following locations as applicable: any conductive or non-conductive point in the control or keyboard areas and any other point of human contact, such as switches, knobs, buttons, indicators, LEDs, seams, slots, grilles, connector shells and other operator accessible areas.

25.5.5 Pulse Application - The ESD discharges shall be applied only to those points and surfaces of the EUT which are accessible to personnel during normal operation (including as installed on aircraft maintenance).

With the ESD generator set at the value recorded during calibration, the ESD generator shall be held perpendicular to the surface to which the discharge is to be applied. The discharge return cable of the generator shall be grounded to the ground plane and kept at a distance of at least 0.2 meters from the EUT and its cabling.

25.5.6 Test Technique - Move the tip of the ESD generator toward the test point at the same speed a human hand would reach to touch an object (approximately 0.3 meters/second) until the generator discharges or until contact is made with the test point. After each discharge or attempted discharge, the ESD generator (discharge electrode) shall be removed from the test point. The generator is then recharged for the next single discharge. This procedure shall be repeated until the 10 discharges or attempted discharges in each polarity and each test point are completed. In the event of no discharge for a selected test point, attempt to locate a discharge point in the area around the test point, e.g., attempt to discharge to multiple points along a section of seam or slot that is identified as a single test point or around all sides of a button that is identified as a single test point.

25.6 Evaluation of the Test Results

Following application of the pulses, DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS, unless specified otherwise.

Shielded Enclosure Wall (Optional)

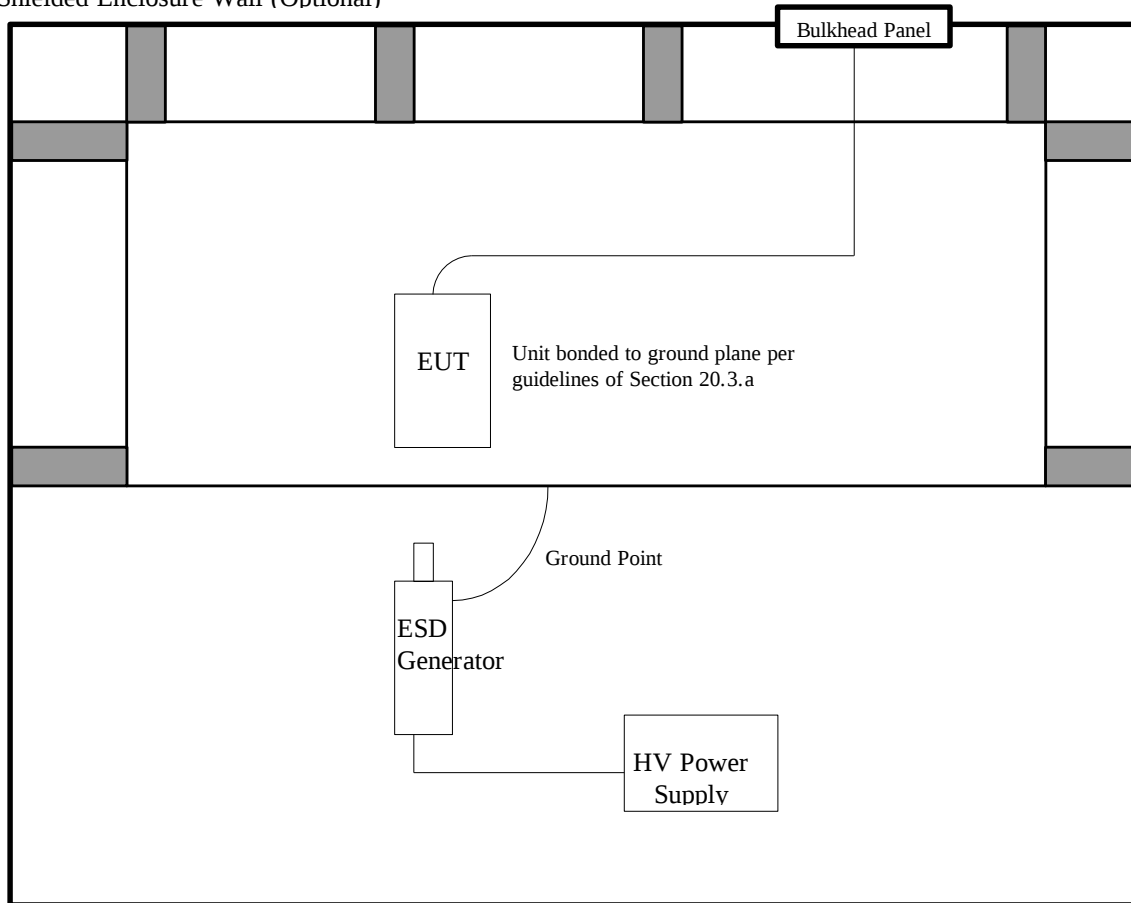


Figure 25-1 Electrostatic Discharge Typical Test Setup

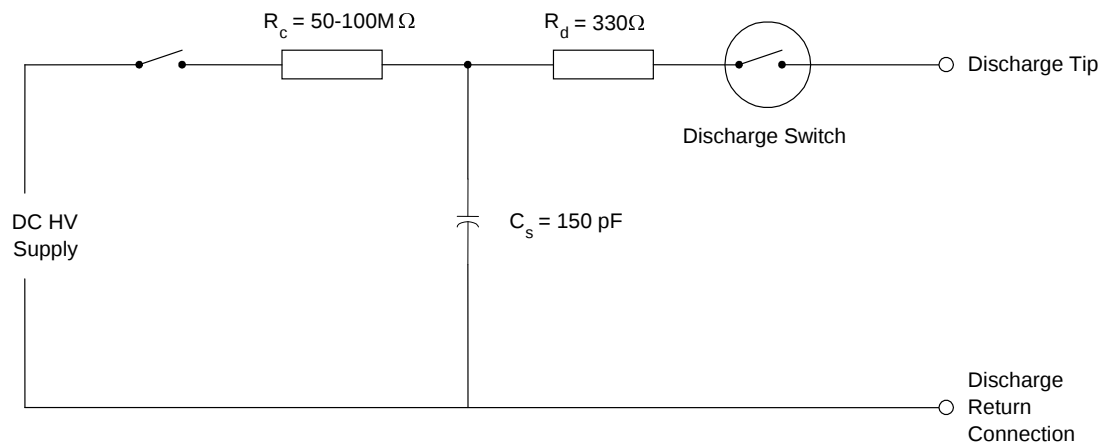
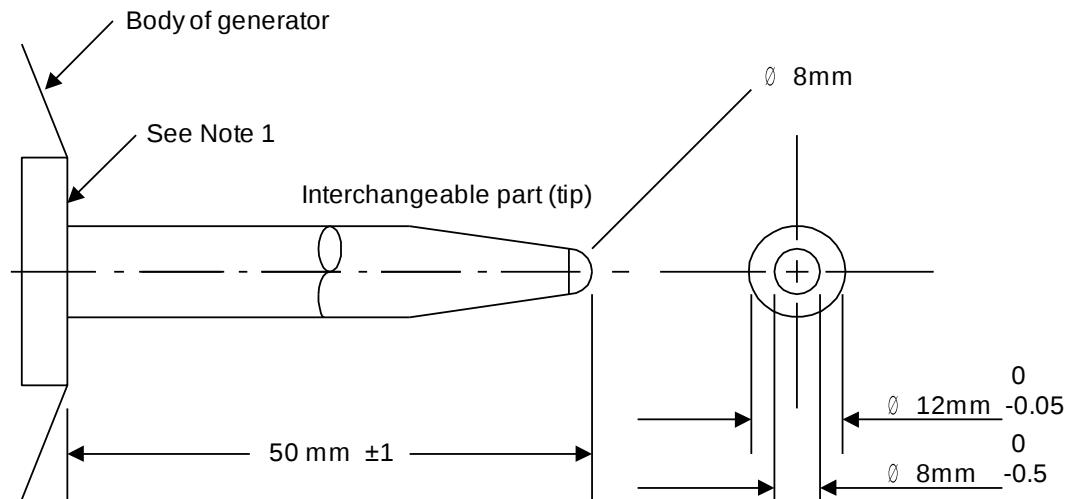


Figure 25-2 Simplified Diagram of the ESD Generator



Note 1 - The discharge switch (e.g., vacuum relay) shall be mounted as close as possible to the tip of the discharge electrode.

Figure 25-3 Discharge Electrode of the ESD Generator

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Section 26

Fire, Flammability

Important Notice

Information pertinent to this test procedure is contained in Sections 1, 2, and 3. Further, Appendix A is applicable for identifying the environmental tests performed.

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26 Fire, Flammability

26.1 Purpose

This section defines test conditions and procedure for Flammability and Fire resistance.

26.2 Applicability

Flammability and fire tests apply to equipment installed on fixed wing propeller driven aircraft, fixed-wing turbojet aircraft, turbofan aircraft, prop fan aircraft, and helicopters.

These tests are applicable for equipment:

- Mounted in pressurized zones
- Mounted in fire zones
- Mounted in non-pressurized, non fire zones

26.3 Equipment Categories

26.3.1 Category A: Fireproof

Intended for equipment installed in fire zone which must function during the first five minutes of fire and which must keep its safety functions for at least fifteen minutes. For fluid handling components, there shall be no leakage to support a flame after the burner has been removed (wetting or droplet that self extinguishes may be acceptable). For air handling components there shall be no leakage that may additionally feed the fire. Equipment shall remain firmly attached to the mounting.

The *fireproof* procedure shall be applied.

Test will be performed on equipment in the operating mode

26.3.2 Category B: Fire Resistant

Intended for equipment installed in fire zone which must not cause a hazardous condition during five minutes of fire without structural degradation. For fluid handling components there shall be no leakage to support a flame after the burner has been removed (wetting or droplet that self extinguishes may be acceptable). For air handling components there shall be no leakage that may additionally feed the fire. In general any leakage of continued burning of the test article at the end of the five minutes would be considered a test failure unless it can be shown that there is not a significant increase in the overall fire hazard. An example of this would be if the fire extinguishing equipment is capable of extinguishing the residual flame.

The *fire resistant* procedure shall be applied.

Test will be performed on equipment in the operating mode.

26.3.3 Category C: Flammability

Applies to enclosures housing electronics and non-metallic material, component parts, sub-assemblies installed in pressurized or non-pressurized zones and non-fire zones. Test to be performed on equipment in a non-operating mode. **The purpose of this test is to check the non-propagation of the flame in the case where ignition would appear inside or outside of the equipment.** Tests will be performed on specimens of material.

The *flammability* procedure shall be applied.

Note: If all materials used in the construction of the equipment can be shown to meet the equivalent vertical and horizontal flammability tests herein, either through composition or previous testing, this test is not required.

Testing is not necessary on enclosures housing electronic or non-metallic material if the following apply:

- 1- The enclosure is constructed of metal (metal finish that is non flammable), on all sides, and has no vent holes
- 2- The enclosure is constructed of metal (metal finish that is non flammable) on five sides and one side is constructed of glass polycarbonate(display) that has met the 12 second vertical test, and has no vent holes.

Small Parts Exemption:

Parts/materials which are considered small may be exempt due to their small size and amount because they would not contribute significantly to the propagation of a fire. Examples of small parts could be: knobs, handles, rollers, fasteners, clips, grommets, rub strips, pulleys, etc. Further definition is offered below:

Table 26-1 Parts/Material Definitions

Size Relation (Typical Usage)
Fits inside a 76.2 mm x 76.2 mm x 12.7 mm (3" x 3" x .5") or 50.8 mm x 50.8 mm x 50.8 mm (2" x 2" x 2") Box without bending of the part
Smaller than 50.8 mm x 76.2 mm x 1.178 mm (label and / or its adhesive) (2" x 3" x .07")
Smaller than 6.35 mm (0.25") Dia. Sphere (drop of thread lock or Nycote)
Smaller than 101.6 mm x 2.286 mm (4" x .09") dia (lacing tape)

Consideration must be given when more than one small part is located in the same proximity with the same or other small parts (one part may ignite the other part) as the combined fuel load may contribute to propagation of a flame, in this case the above small parts exemption would not apply. Small parts exemption does not apply to wire and cable.

26.4 Fire proof/Resistant Test procedure

26.4.1 Apparatus

Fire proof/resistant test: Burner with a flame standardized of $1100^{\circ}\text{C} \pm 80^{\circ}\text{C}$. A modified gun type burner with extension tube shall be used with kerosene (see Figure 26-16). Adjustment of fuel flow and air is allowed during the pre-test calibration only to achieve the required characteristics of the flame.

26.4.2 Burner Calibration

The following burner calibration steps shall be taken after a five minute warm-up period. Do not expose the heat transfer copper tube to the flame during this warm-up period to avoid carbon build-up on the tube.

26.4.3 Flame Temperature

The flame temperature shall be adjusted to provide $1100^{\circ}\text{C} \pm 80^{\circ}\text{C}$ as measured by a thermocouple rake placed 100 mm (nominal) from the burner. The equipment under test must be placed 100 mm (nominal) from the burner during the test. The rake consists of seven thermocouples centered across the torch at a distance of 100 mm (nominal) in front of the nozzle (see Figure 26-15). Temperature data shall be taken at least every 30 seconds for a three-minute period during the pre and post test flame temperature calibration to ensure steady-state conditions.

26.4.4 Flame Intensity

The flame heat content is required to provide 4,500 Btu/hr minimum input to a 380 mm exposed length of 127 mm by 0.81 mm (0.5" by 0.032") refrigeration type copper tubing with a water flow rate of one gallon/minute (500 lb/hr). This measurement is taken at the same location in the flame where the requirements of Flame Temperature are satisfied. The temperature delta multiplied by the water flow rate through the tube (500 lb/hr) = the Btu/hr input into the tube.

- 1- Clean the copper tubing with fine steel wool before the pre test calibration.
- 2- The supplied water temperature shall be between 10°C and 21°C .
- 3- Water flow rate through tube shall be adjusted to 500 lb/hr minimum.
- 4- Transfer the burner to the heat transfer tube and begin a three-minute warm-up period to ensure stable conditions.
- 5- Record inlet and outlet water temperature at least every thirty seconds for a three-minute period.
- 6- Perform calculations to ensure minimum requirements are met. Refer to Figure 26-17 and Figure 26-18 for additional details on the heat flux measurement apparatus.

26.4.5 Steady State Operating Conditions

Steady state operating conditions should be chosen to represent the worst case scenario for the unit under test. Considerations shall include the minimal cooling, highest pressures, and maximum working fluid temperatures the product may experience. It is not required for the chamber to simulate the maximum ambient temperature of the equipment, room temperature ambient is sufficient. Ground idle conditions are often chosen to represent a worst case scenario.

26.4.6 Flame Direction and Location(s) Determination

The test flame impingement location(s) on the test article is established via analysis based on most critical location(s) with respect to the fire source and the most susceptible location(s) on the test article considering critical circuitry, fluid flow, wall thickness, seals, etc. The most likely flame direction (i.e. bottom of unit) may also be considered in the impingement location analysis but this may result in limiting future changes/use of unit. The flame must impinge the critical location(s) on the test article determined from the impingement analysis. This location shall be positioned at the same distance and height as the calibration was performed. For equipment determined to have more than one critical location, additional tests may be required if a single, representative impingement location cannot be identified to adequately address all locations. If multiple locations are required, multiple test articles may be used but are not required.

26.4.7 Fire Proof Test

Perform the following tests using the flame adjusted as detailed above. Connect the equipment so that it is both powered on and functional. All connections (electrical, fluid, pneumatic, etc.) to the test article must be of the type design configuration. The use of non-type design cables, bundles, and connectors is permitted at locations not directly interfacing with the test article. All non-type design hardware may be protected during the test as long as the protection provided does not interfere with the test article flame exposure. High temperature ceramic insulation is recommended to protect non type design cables and tubing.

With the equipment operating, apply the normal flame for fifteen minutes.

ONLY DURING THE FIRST FIVE MINUTES OF THE TEST DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

At the completion of the test, without extinguishing the flame, a post test calibration of the flame temperature shall be performed. After the last ten minutes the equipment shall be inspected and shall show no evidence of continued combustion or flame propagation and shall be self extinguishing.

Caution: In particular cases (e.g. systems of fluids), a specific procedure could be specified by the aircraft manufacturer.

26.5 Fire Resistant Test

Perform the following tests using the appropriate test flame of paragraph 26.4.

Connect the equipment so that it is both powered on and functional. The use of non-type design cables, bundles, and connectors is permitted. All non-type design hardware may be protected during the test as long as the protection provided does not interfere with the test article flame exposure. High temperature ceramic sleeving is recommended to protect non-type design cables and tubing.

After the pre-test flame calibration and with the equipment operating, apply the flame for five minutes.

DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS DURING THE TEST OR DEMONSTRATE THAT A NON-

HAZARDOUS CONDITION IS MAINTAINED DURING THE FIVE MINUTE PERIOD.

At the completion of the test, without extinguishing the flame, a post test calibration of the flame temperature shall be performed. In addition, the equipment shall be inspected and shall show no structural default or evidence of continued combustion or flame propagation and shall be self-extinguishing. In general any leakage or continued burning of the test article at the end of the five minutes would be considered a test failure unless it can be shown that there is not a significant increase in the overall fire hazard.

CAUTION: In particular cases (e.g. systems of fluids), a specific procedure could be specified by the aircraft or engine manufacturer.

26.5.1 Data Recording

- a) Data recording of key parameters (T/C's, flows, pressures, etc) throughout the test is required, including key parameters for calibration determination.
- b) The entire test is to be video recorded. Multiple views are recommended. Post test photos are required also.

26.6 Flammability Test

26.6.1 Determination of the Type of Test

The following table defines which test shall be applied to demonstrate that the equipment complies with flammability requirements. Material sample size to be tested is listed in each method section.

Table 26-2 Type of Test Determination

Components	Method	Paragraph
All materials other than rubber or elastomer parts, wire and cable	Vertical 12 second bunsen burner test	26.6.2
Rubber or elastomer parts	Horizontal bunsen burner test	26.6.3
Wire and cable	60 degree bunsen burner test	26.6.4

26.6.2 Vertical Bunsen Burner Test for Cabin and Cargo Compartment Materials**26.6.2.1 Definitions****26.6.2.1.1 Ignition Time**

Ignition time is the length of time the burner flame is applied to the specimen.

26.6.2.1.2 Flame Time

Flame time is the time in seconds that the specimen continues to flame after the burner flame is removed from beneath the specimen. Surface burning that results in a glow but not in a flame is not included.

26.6.2.1.3 Drip Flame Time

Drip flame time is the time in seconds that any flaming material continues to flame after falling from the specimen to the floor of the chamber. If no material falls from the specimen, the drip flame time is reported to be 0 seconds, and the notation “No Drip” is also reported. If there is more than one drip, the drip flame time reported is that of the longest flaming drip. If succeeding flaming drips reignite earlier drips that flamed, the drip flame time reported is the total of all flaming drips.

26.6.2.1.4 Burn length

Burn length is the distance from the original specimen edge to the farthest evidence of damage to the test specimen due to that area’s combustion including areas of partial consumption, charring, or embrittlement but not including areas sooted, stained, warped, or discolored nor areas where material has shrunk or melted away from the heat.

26.6.2.2 Test Apparatus**26.6.2.2.1 Test Cabinet**

Tests will be conducted in a draft-free cabinet fabricated in accordance with

FIGURE **26-1**, Figure 26-2 and Figure 26-3 or equivalent. Other cabinets may be used if they are draft free and have enough air to allow complete combustion. It is suggested that the cabinet be located inside an exhaust hood to facilitate clearing the cabinet of smoke after each test. Stainless steel or other corrosion-resistant metal 0.04 inch (1 mm) thick will be used for the bottom surface of the chamber.

26.6.2.2.2 Specimen Holder

The specimen holder will be fabricated of corrosion-resistant metal in accordance with Figure 26-3 or the equivalent. The holder will be able to accommodate specimens up to 1 inch (25 mm) thick.

26.6.2.2.3 Burner

The burner will be a Bunsen or Tirrill type, have a 3/8-inch (10-mm) inside diameter barrel, and be equipped with a needle valve located at the bottom of the burner barrel to adjust the gas flow rate and, thereby, adjust the flame height. There will be a means provided to move the burner into and out of test position when the cabinet door is closed.

26.6.2.2.3.1 Burner Fuel

Methane gas of 99 percent minimum purity shall be used. It can be used without adding air through the aspirating holes at the bottom of the burner barrel; e.g., a pure diffusion flame may be used.

26.6.2.2.3.2 Plumbing for Gas Supply

The necessary gas connections and the applicable plumbing will be essentially as shown in Figure 26-4. A control valve system with a delivery rate designed to furnish gas to the burner under a pressure of $2\frac{1}{2} \pm \frac{1}{4}$ psi (17 ± 2 kPa) at the burner inlet will be installed between the gas supply and the burner.

26.6.2.2.3.3 Flame Height Indicator

A flame height indicator may be used to aid in setting the height of the flame. A suitable indicator has a prong extending 1.5 inches (38 mm) above the top of the burner barrel, is attached to the burner barrel, and spaced 1 inch (25 mm) from the burner barrel, as shown in Figure 26-4. If using methane as the burner fuel, it is desirable to have two prongs for measuring the flame height, one prong to indicate the height of the inner cone of the flame and one prong to indicate the height of the tip of the flame. For methane, it has been determined that when the height of the inner cone is $\frac{7}{8}$ inch (22 mm) and the tip of the flame is 1.5 inches (38 mm) long, the proper flame profile is achieved.

26.6.2.2.4 Timer

A stopwatch or other device, calibrated to the nearest 0.1 second, will be used to measure the time of application of the burner flame, the flame time, and the drip flame time.

26.6.2.2.5 Ruler

A ruler or scale graduated to the nearest 0.1 inch (2.5 mm) will be provided to measure the burn length.

26.6.2.3 Test Specimens

26.6.2.3.1 Specimen Selection

Specimens tested will be either cut from a fabricated part as installed in the aircraft or cut from a section simulating a fabricated part, e.g., cut from a flat sheet of material or from a model of the fabricated part. The specimen may be cut from any location in the fabricated part. However, the edge to which the burner is applied must not consist of the finished or protected edge of the specimen. Fabricated units, such as sandwich panels, will not be separated into individual component layers for testing.

26.6.2.3.2 Specimen Number

Each separate set of specimens prepared for testing will consist of at least three specimens (multiple places).

26.6.2.3.3 Specimen Size

The specimen will be a rectangle at least 3 by 12 inches (75 by 305 mm), unless the actual size used in the aircraft is smaller and it is not possible to acquire a larger sample of the material. Since the allowable burn length is 8 inches a sample less than 8 inches would not meet the pass requirements if burned completely.

26.6.2.3.4 Specimen Thickness

The specimen thickness will be the same as that of the part qualified for use in the airplane, with the following exceptions:

1. If the part construction is used in several thicknesses, the minimum thickness will be tested.
2. Foam parts that are thicker than 1/2 inch (13 mm) will be tested in 1/2 -inch (13 mm) thicknesses.
3. Parts that are smaller than the size of a specimen and cannot have specimens cut from them may be tested using a flat sheet of the material used to fabricate the part in the actual thickness used in the aircraft.

26.6.2.4 Conditioning

Specimens will be conditioned at $70^{\circ} \pm 5^{\circ}\text{F}$ ($21^{\circ} \pm 3^{\circ}\text{C}$) and $50\% \pm 5\%$ relative humidity for 24 hours minimum. Remove only one specimen at a time from the conditioning environment immediately before testing.

26.6.2.5 Procedure**26.6.2.5.1 Burner Adjustment**

1. If using methane as the burner fuel, ensure that the air supply to the burner is shut off.
2. Open the stopcock in the gas line fully and light the burner.
3. Adjust the needle valve on the burner to achieve the proper 1.5-inch (38-mm) flame height, in accordance with Section 26.6.2.2.3.3.

26.6.2.6 Test Procedure

1. Place the burner at least 3 inches (76 mm) from where the specimen will be located during the test.
2. Insert the specimen with its lower edge 3/4 inch (19 mm) above the level of the top of the burner.
3. Close the cabinet door, and keep it closed during the test.
4. Start the timer immediately upon positioning the burner. Position the burner so that the flame impinges on the midpoint of the lower edge of the front face of the test specimen. This flame position should be used for all specimen thicknesses (See FIGURE 26-5).
5. Apply the flame for 12 seconds and then withdraw it by moving the burner at least 3 inches (76 mm) from the specimen or by turning the gas off.
6. If flaming material falls from the test specimen, determine the drip flame time for the specimen.
7. Determine the flame time for the specimen.

8. After all flaming ceases, open the cabinet door slowly to clear the test cabinet of fumes and smoke. The exhaust fan may be turned on to facilitate clearing smoke and fumes.
9. Remove the specimen and determine the burn length. To aid in determining the burn length, a dry soft cloth or tissue, or a soft cloth or tissue dampened with a moderate solvent, such as methyl, ethyl, or isopropyl alcohol (which does not dissolve or attack the specimen material), may be used to remove soot and stain particles from tested specimens.
10. Remove any material from the bottom of the cabinet that fell from the specimen. If necessary, clean the test cabinet window and/or back face mirror prior to testing the next specimen.

26.6.2.7 Report

26.6.2.7.1 Material Identification

Fully identify the material tested, including thickness. Also, include the specimen length if a 12-inch specimen is not available.

26.6.2.7.2 Test Results

Ignition Time - Report the ignition time applied was 12 seconds.

Flame Time - Report the flame time for each specimen tested. Determine and record the average value for flame time (see Section 26.6.2.1.2).

Drip Flame Time - Report the drip flame time for each specimen tested. Determine and record the average value for the drip flame time (see Section 26.6.2.1.3). For specimens that have no drips, record "0" for the drip flame time and also record "No Drips."

Burn Length - Report the burn length to the nearest 0.1 inch for each specimen tested. Determine and record the average value for burn length.

26.6.2.8 Requirements

26.6.2.8.1 Flame Time

The average flame time for all of the specimens tested will not exceed 15 seconds for the 12-second test.

26.6.2.8.2 Drip Flame Time

The average drip extinguishing time for all of the specimens tested will not exceed 5 seconds for the 12-second vertical test.

26.6.2.8.3 Burn Length

The average burn length for all of the specimens tested will not exceed 8 inches (203 mm) for the 12-second vertical test.

26.6.3 Horizontal Bunsen Burner Test for Miscellaneous Materials**26.6.3.1 Definitions****26.6.3.1.1 Ignition Time**

Ignition time is the length of time the burner flame is applied to the specimen. For this test, the ignition time is 15 seconds.

26.6.3.1.2 Burn Rate

Burn rate is the rate at which a flame front moves over a specified distance on a test specimen, under specified test conditions. In this test, it is the rate with which a flame front moves across a test specimen mounted horizontally.

26.6.3.2 Apparatus**26.6.3.2.1 Test Cabinet**

Tests will be conducted in a draft-free cabinet fabricated in accordance with Figure 26-6, Figure 26-7 and Figure 26-8 or other equivalent enclosure. Other cabinets may be used if they are draft free and have enough air to allow complete combustion. It is suggested that the cabinet be located inside an exhaust hood to facilitate clearing the cabinet of smoke after each test. Stainless steel or other corrosion resistant metal, 0.04 inch (1 mm) thick will be used for the bottom surface of the chamber.

26.6.3.2.2 Specimen Holder

A specimen holder fabricated of corrosion-resistant metal in accordance with Figure 26-9 will be used. When performing the tests, the specimen will be mounted in the frame so that the two long edges are held securely. The exposed area of the specimen will be 2 inches (51 mm) in width and 12 inches (305 mm) in length.

26.6.3.2.3 Burner

The burner will be a Bunsen or Tirrill type, have a 3/8-inch (10-mm) inside diameter barrel, and will be equipped with a needle valve located at the bottom of the burner barrel to adjust the gas flow rate and, thereby, adjust the flame height. There will be a means provided to move the burner into and out of test position when the cabinet door is closed.

26.6.3.2.4 Burner Fuel

Methane gas (99 percent minimum purity) will be used. . It can be used without adding air through the aspirating holes at the bottom of the burner barrel, i.e., a pure diffusion flame may be used.

26.6.3.2.5 Plumbing for Gas Supply

The necessary gas connections and the applicable plumbing will be essentially as shown in Figure 26-10. A control valve system with a delivery rate designed to furnish gas to the burner under a pressure of $2\frac{1}{2} \pm \frac{1}{4}$ psi (17 ± 2 kPa) at the burner inlet will be installed between the gas supply and the burner.

26.6.3.2.6 Flame Height Indicator

A flame height indicator may be used to aid in setting the height of the flame. A suitable indicator has a prong extending 1.5 inches (38 mm) above the top of the burner barrel, is attached to the burner barrel, and spaced 1 inch (25 mm) from the burner barrel, as shown in Figure 26-10. When using methane as the burner fuel, it is desirable to have two prongs for measuring the flame height, one prong to indicate the height of the inner cone of the flame and one prong to indicate the height of the tip of the flame. For methane, it has been determined that when the height of the inner cone is 7/8 inch (22 mm) and the tip of the flame is 1.5 inches (38 mm) long, the proper flame profile is achieved.

26.6.3.3 Timer

A stopwatch or other device, calibrated to the nearest 0.1 second, will be used to measure the time of application of the burner flame, the flame time, and the drip flame time.

26.6.3.4 Ruler

A ruler or scale graduated to the nearest 0.1 inch (2.5 mm) will be provided to measure gage marks and flame front position.

26.6.3.5 Test Specimens

26.6.3.5.1 Specimen Selection

Specimens tested will be either cut from a fabricated part as installed in the aircraft or cut from a section simulating a fabricated part, e.g., cut from a flat sheet of material or from a model of the fabricated part. The specimen may be cut from any location in the fabricated part. Fabricated units, such as sandwich panels, will not be separated into individual component layers for testing.

26.6.3.5.2 Specimen Number

Each separate set of specimens prepared for testing will consist of at least three specimens (multiple places where possible).

26.6.3.5.3 Specimen Size

The specimen will be a rectangle at least 3 by 12 inches (76 by 305 mm).

26.6.3.5.4 Specimen Thickness

The specimen thickness will be the same as that of the part qualified for use in the aircraft, with the following exceptions:

- 1) The specimen thickness must be no thicker than the minimum thickness to be qualified for use in the aircraft. The specimen thickness will not exceed 1/8 inch (3 mm).
- 2) Parts that are smaller than the size of a specimen and cannot have specimens cut from them may be tested using a flat sheet of the material used to fabricate the part in the actual thickness used in the aircraft. The sheet thickness will not exceed

1/8 inch (3 mm) if the test being run is the 4 inches per minute horizontal burn rate test.

26.6.3.5.5 Specimen Preparation

Mark gauge lines on the back surface (opposite the surface to be exposed to the flame) of the specimen 1.5 inches (38 mm) and 11.5 inches (292 mm) from the end of the specimen that will be subjected to the flame.

- 1) A fine-gauge wire mesh with large openings can be used to support test specimens that sag severely during testing so that the flame propagation may be determined accurately.

26.6.3.6 Conditioning

Condition specimens at 70 $\pm$ 5°F (21 $\pm$ 3°C) and 50% $\pm$ 5% relative humidity for 24 hours minimum. Remove only one specimen at a time from the conditioning environment immediately before being tested.

26.6.3.7 Procedure

26.6.3.7.1 Burner Adjustment

- 1) If using methane as the burner fuel, ensure that the air supply to the burner is shut off.
- 2) Open the stopcock in the gas line fully and light the burner.
- 3) Adjust the needle valve on the burner to achieve the proper 1.5-inch (38-mm) flame height in accordance with section 26.6.3.2.6.
- 4) Close the cabinet door, and keep it closed during the test.
- 5) Start the timer immediately upon positioning the burner. Position the burner so that the centerline of the burner orifice is in line with the edge of the specimen holder and the centerline of the width of the specimen (See Figure 26-11).
- 6) Apply the flame for 15 seconds and then withdraw it by moving the burner at least 3 inches (76 mm) from the specimen or by turning the gas off.
- 7) Note the times and/or locations on the specimen at which the following events occur:
 - a. If the flame front crosses the 1.5-inch (38-mm) gauge line, note the elapsed time in seconds, $t_e(1 \frac{1}{2})$, at which the crossing occurs.
 - b. If the flame front crosses the 11.5-inch (292-mm) gauge line, note the elapsed time in seconds, $t_e(11 \frac{1}{2})$, at which the crossing occurs.
 - c. If the specimen burns very slowly so that the flame front does not reach the 11.5-inch (292-mm) gauge line within 4 minutes after it passes the 1.5-inch (38-mm) gauge line, note the position in inches, d_f , of the flame front from the ignited end of the specimen and the elapsed time in seconds, $t_e(f)$, and terminate the test.

- 8) After all flaming ceases, open the cabinet door slowly to clear the test cabinet of fumes and smoke. The exhaust fan may be turned on to facilitate clearing of smoke and fumes. Remove any material from the bottom of the cabinet that fell from the specimen.
- 9) If necessary, clean the test cabinet window prior to testing the next specimen.

26.6.3.8 Test Results—Burn Rate

Determine the burn rate as follows:

- 1) If the flame front self-extinguished before crossing the 11.5-inch (292-mm) gauge line, record the burn rate as zero.
- 2) If the flame crosses the 11.5-inch (292-mm) gauge line, determine and record the burn rate as:

Burn rate (in/min) = $600 / t_e(10)$, where $t_e(10) = t_e(11 \frac{1}{2}) - t_e(1 \frac{1}{2})$ = time in seconds for the flame front to burn from the 1.5-inch (38-mm) gauge line to the 11.5-inch (292-mm) gauge line.

- 3) If the specimen burned very slowly (see Section 26.6.3.7.1, Step 7), the burn rate may be estimated and recorded as:

$$\text{Burn Rate (in/min)} = 60 \times \frac{(d_f - 1.5)}{(t_e(f) - t_e(1\frac{1}{2}))}$$

26.6.3.9 Report

26.6.3.9.1 Material Identification

Fully identify the material tested, including thickness.

26.6.3.9.2 Test Results

Report the burn rate from Section 26.6.3.1.2 for each specimen tested. Determine and record the average value for burn rate.

26.6.3.10 Requirements

26.6.3.10.1 Burn Rate

The average burn rate for all the specimens tested will not exceed 4 inches/minute

26.6.4 60-Degree Bunsen Burner Test for Electric Wire

26.6.4.1 Definitions

26.6.4.1.1 Ignition Time

Ignition time is the length of time the burner flame is applied to the specimen. The ignition time for this test is 30 seconds.

26.6.4.1.2 Flame Time

Flame time is the time in seconds that the specimen continues to flame after the burner flame is removed from beneath the specimen. Surface burning that results in a glow but not in a flame is not included.

26.6.4.1.3 Drip Flame Time

Drip flame time is the time in seconds that any flaming material continues to flame after falling from the specimen to the floor of the chamber. If there is more than one drip, the drip flame time reported is that of the longest flaming drip. If succeeding flaming drips reignite earlier drips that flamed, the drip flame time reported is the total of all flaming drips.

26.6.4.1.4 Burn Length

Burn length is the length of damage along the wire above and below the point of burner flame impingement and due to that area's combustion, including areas of partial consumption, charring, or embrittlement, but not including areas sooted, stained, warped, or discolored nor areas where material has shrunk or melted away from the heat.

26.6.4.2 Apparatus**26.6.4.2.1 Test Enclosure and Setup**

Tests will be conducted in a cabinet fabricated of sheet metal, approximately 24 inches (610 mm) high by 12 inches (305 mm) wide by 12 inches (305 mm) deep and open at the front and top. External conditions around the cabinet will be such that the cabinet is free of drafts during a test, but sufficient airflow will be available for complete combustion. Other cabinets may be used if they are draft free and have enough air to allow complete combustion. It is suggested that the cabinet be located inside an exhaust hood to facilitate removal of smoke and fumes after each test.

26.6.4.2.2 Specimen Holder

A specimen holder fabricated of corrosion-resistant metal in accordance with Figure 26-12 will be used. The specimen holder will be placed so that the specimen is maintained at an angle of 60 degrees with the horizontal and is positioned parallel to and 6 inches (152 mm) back from the front of the enclosure.

26.6.4.2.2.1 Clamp and Pulley

The specimen will be attached to the specimen holder by a clamp at the lower end and a pulley or rod at the upper end. The span between the clamp and the rod or pulley will be 24 inches (610 mm).

26.6.4.2.2.2 Weight

A weight will be attached to the free end of the specimen to keep the specimen taut during the test (See Figure 26-12). Suggested weights for various wire sizes are shown in Table 26-3.

Table 26-3 Wire Size and Weight Suggestions

AWG	Pounds	Kg
20	0.8	0.4
14	2.0	0.9
8	3.0	1.4
1/0	11.0	5.0

26.6.4.2.3 Burner

The burner will be a Bunsen or Tirrill type, have a 3/8-inch (10-mm) inside diameter barrel and be equipped with a needle valve at the bottom of the burner barrel to adjust the gas flow rate (see Figure 26-13). A means will be provided to move the burner into and out of the test position. Mounting the burner on a fixture that allows it to be rotated in the horizontal plane is suggested.

26.6.4.2.3.1 Burner Fuel

Methane gas of 99 percent minimum purity shall be used. It can be used without adding air through the aspirating holes at the bottom of the burner barrel, i.e., a pure diffusion flame may be used.

26.6.4.2.3.2 Plumbing for Gas Supply

The necessary gas connections and the applicable plumbing will be essentially as shown in Figure 26-13. A control valve system with a delivery rate designed to furnish gas to the burner under a pressure of $2 \frac{1}{2} \pm \frac{1}{4}$ lb/ft² (17 ± 2 kPa) at the burner inlet will be installed in between the gas supply and the burner.

26.6.4.2.3.3 Flame Height Indicator

A flame height indicator may be used to aid in setting the height of the flame. A suitable indicator has a prong 3 inches (76 mm) above the top of the barrel, is attached to the burner barrel, spaced 1 inch (25 mm) from the burner barrel, and extends above the burner, as shown in Figure 26-2. It is desirable to have two prongs to measure flame height, one prong to indicate the height of the inner cone of the flame and one prong to indicate the height of the tip of the flame. For this test, it has been determined that when the height of the inner cone is 1 inch (25 mm) and the tip of the flame is 3 inches (76 mm), the proper flame profile is achieved.

26.6.4.2.4 Timer

A stopwatch or other device graduated to the nearest 0.1 second will be used to measure the time of application of the burner flame, the flame time, and the drip flame time.

26.6.4.2.5 Ruler

A ruler or scale graduated to the nearest 0.1 inch (2.5 mm) will be provided to measure the burn length.

26.6.4.3 Test Specimens**26.6.4.3.1 Specimen Number**

Each separate set of specimens prepared for testing will consist of at least three specimens (multiple places).

26.6.4.3.2 Specimen Length

The specimens will be cut to a length of 30 inches (762 mm). The specimen span between the lower clamp and upper pulley or rod will be 24 inches (610 mm).

26.6.4.3.3 Specimen Preparation

Make a gauge mark 8 inches (203 mm) from one end of each specimen.

26.6.4.4 Conditioning

Condition specimens at $70 \pm 5^{\circ}\text{F}$ ($21 \pm 3^{\circ}\text{C}$) and $50\% \pm 5\%$ relative humidity for 24 hours minimum unless otherwise specified. Remove only one specimen at a time from the conditioning environment immediately before being tested.

26.6.4.5 Procedure**26.6.4.5.1 Burner Adjustment**

- 1) If using methane as the burner fuel, ensure that the air supply to the burner is shut off.
- 2) Open the stopcock in the gas line fully and light the burner.
- 3) Adjust the burner flame to obtain a flame profile so that the outer cone of the flame is 3 inches (76 mm) in length and the inner cone is approximately 1 inch (25 mm) in length. The proper flame length will be obtained by adjusting the needle valve on the burner controlling the gas flow rate.
- 4) Burner Placement
For the test, place the burner into position so that the top end of the burner barrel is 1 inch from the mark on the specimen, and the centerline of the burner barrel is perpendicular to the specimen and intersects the specimen at the mark (See Figure 26-12).

26.6.4.5.2 Test Procedure

- 1) Place the burner at least 3 inches (76 mm) from where the specimen will be located during the test.
- 2) The timer must be started immediately upon positioning the burner. Position the burner as described in section 26.6.4.2.3.3 so that the tip of the inner cone of the burner flame contacts the gauge mark on the wire.
- 3) Apply the flame for 30 seconds, and then withdraw it.
- 4) If flaming material falls from the test specimen, note the drip flame time for the specimen (see Section 26.6.4.1.3).

- 5) Determine the flame time for the specimen (see Section 26.6.4.1.2).
- 6) After all flaming ceases, remove the specimen and determine the burn length (see Section 26.6.4.1.4). To facilitate determining the burn length, a dry soft cloth or tissue or a soft cloth or tissue dampened with a moderate solvent that does not dissolve or attack the specimen material, such as alcohol, may be used to remove soot and stain particles from tested specimens.
- 7) Remove any material from the bottom of the cabinet that fell from the specimen.

26.6.4.6 Report

26.6.4.6.1 Material Identification

Fully identify the wire tested.

26.6.4.6.2 Test Results

- 1) Report the flame time for each specimen tested. Determine and record the average value for flame time.
- 2) Report the drip flame time for each specimen tested. Determine and record the average value for drip flame time. For specimens that have no drips, record “0” for the drip flame time and also record “No Drips.”
- 3) Report the burn length for each specimen tested. Determine and record the average value for burn length.

26.6.4.7 Requirements

26.6.4.7.1 Extinguishing Time

The average extinguishing time for all the specimens tested will not exceed 30 seconds.

26.6.4.7.2 Drip Extinguishing Time

The average drip extinguishing time for all the specimens tested will not exceed 3 seconds.

26.6.4.7.3 Burn Length

The average burn length for all the specimens tested will not exceed 3 inches (76 mm).

26.6.4.7.4 Wire Breakage

It will not be considered a failure if the wire breaks during the test.

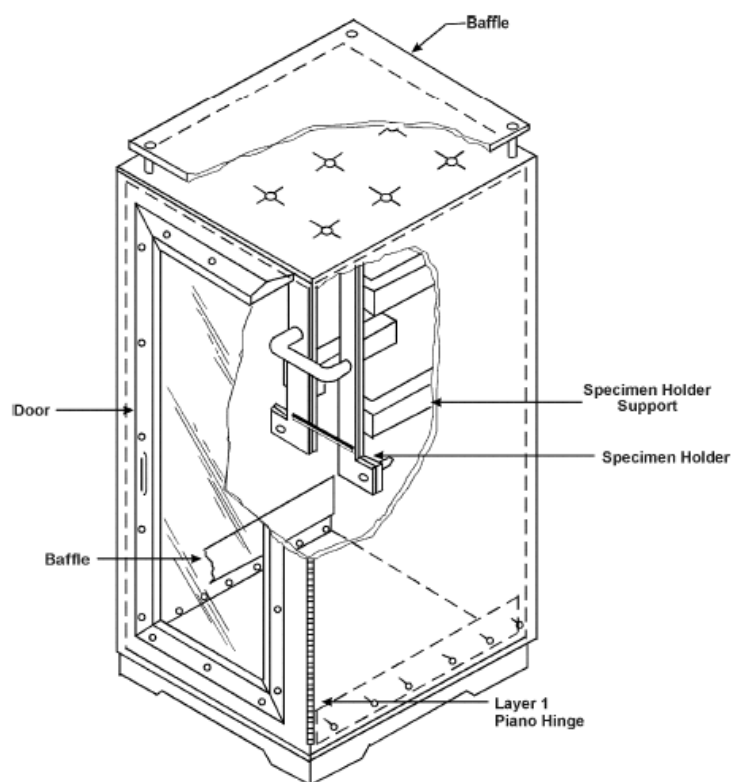
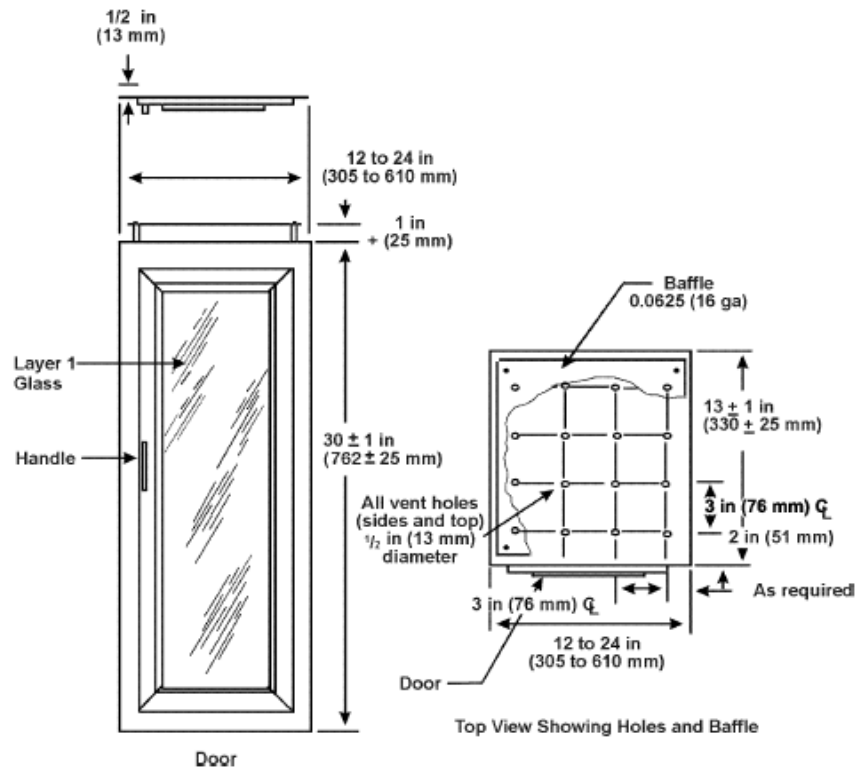


FIGURE 26-1 Vertical Bunsen Burner Test Cabinet

**FIGURE 26-2****Front and Top View of Vertical Bunsen Burner Test Cabinet**

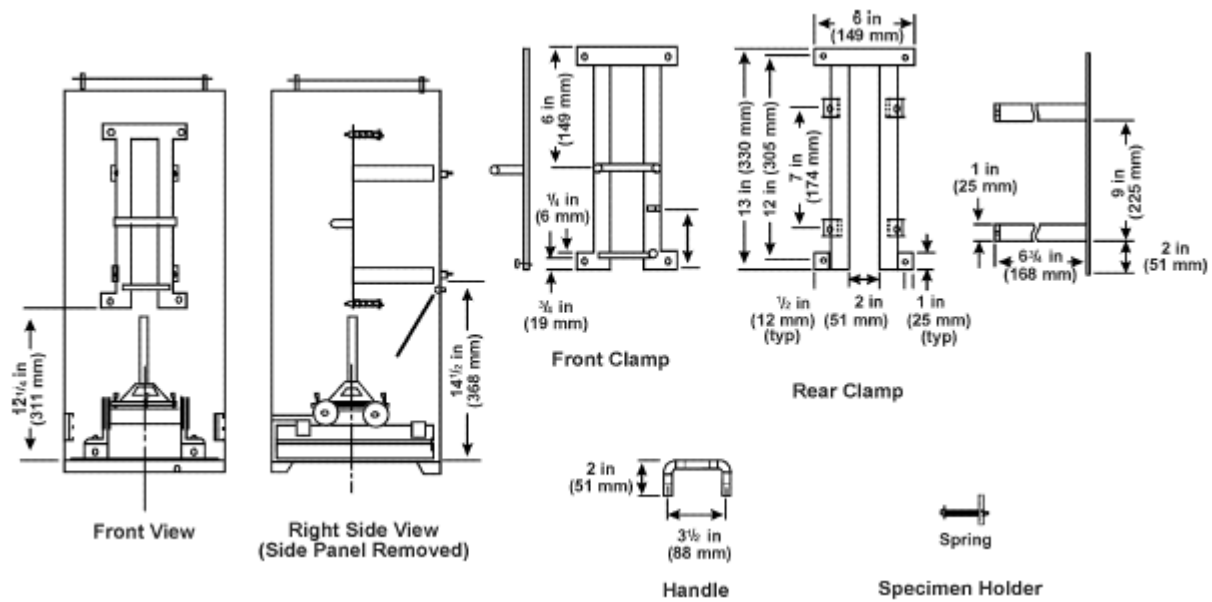


FIGURE 26-3 Vertical Bunsen Burner Test Specimen Holder

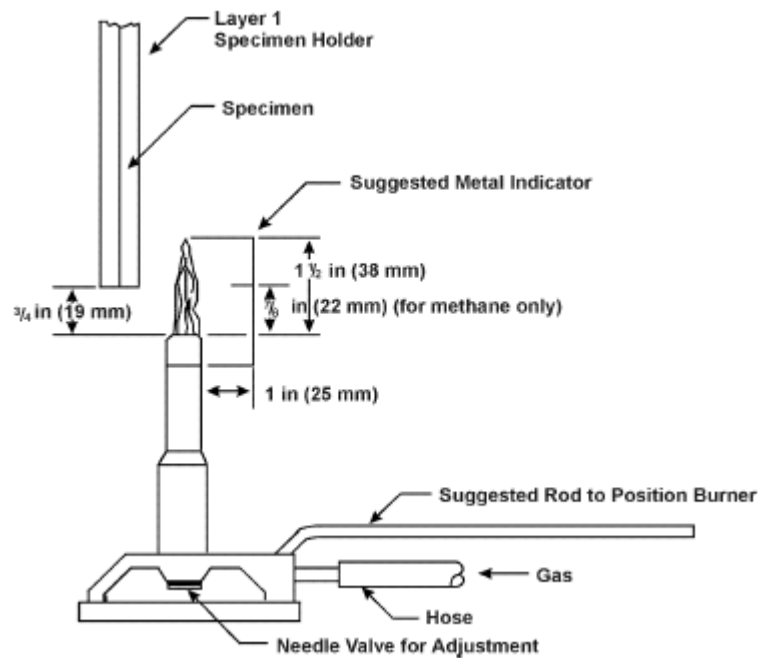


FIGURE 26-4 Burner Plumbing and Burner Flame Height Indicator

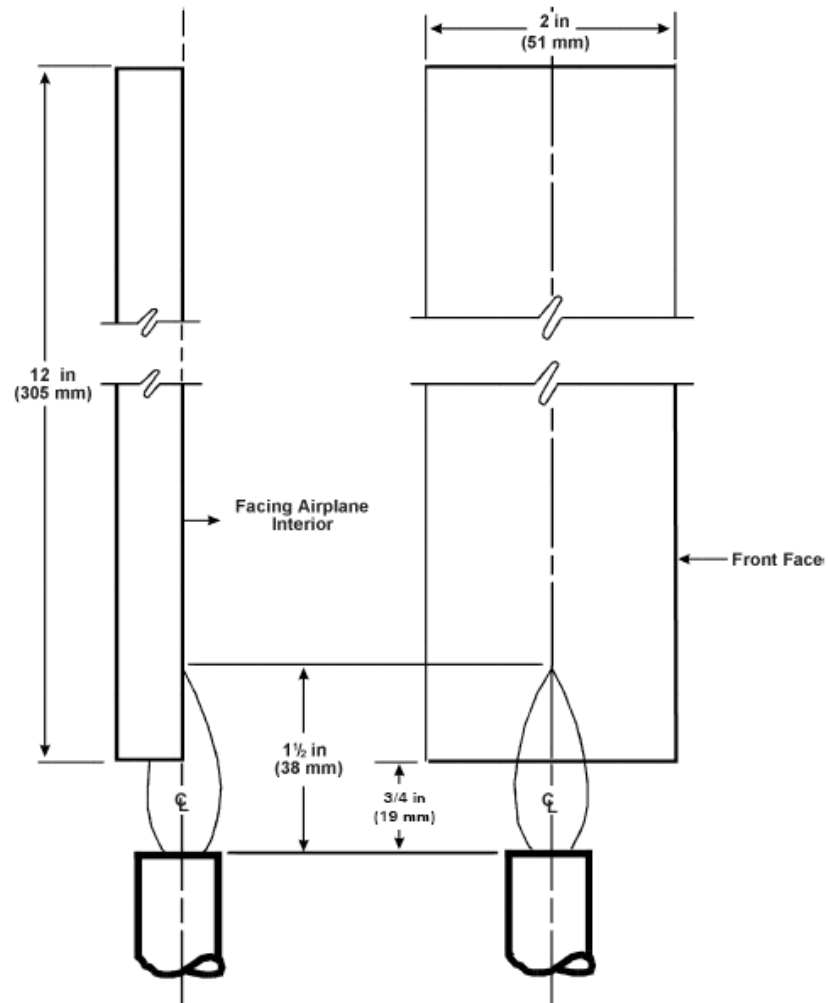


FIGURE 26-5 Flame Position on Vertical Specimens

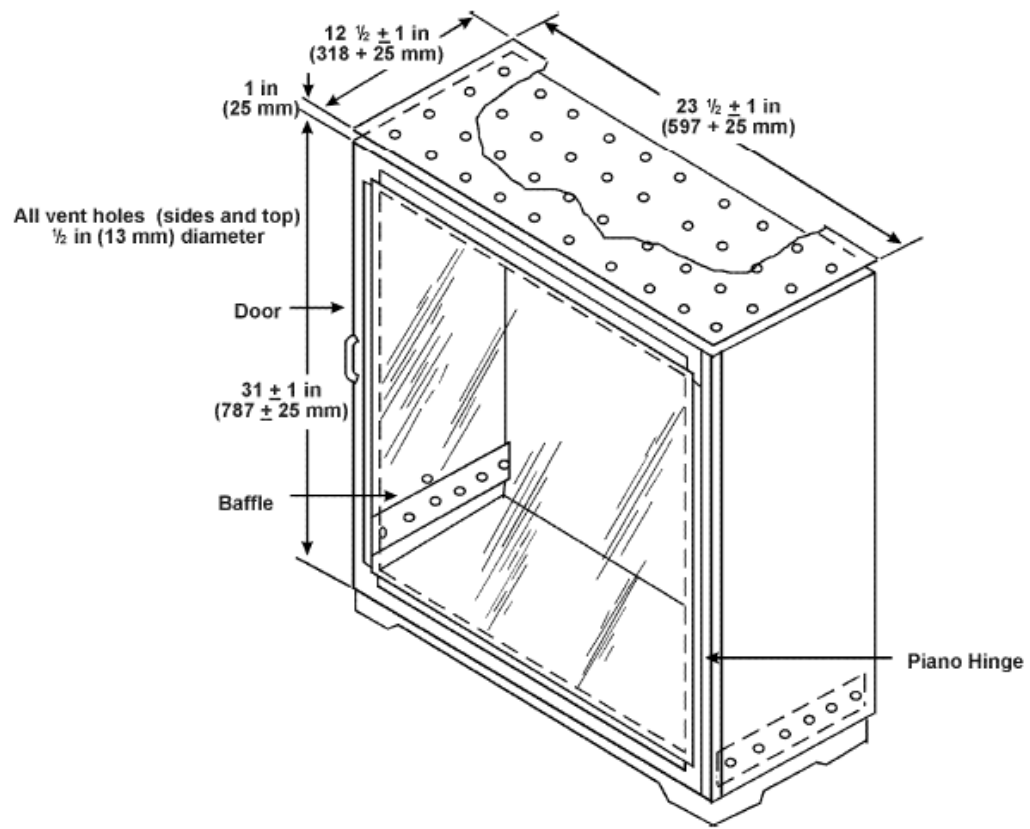


FIGURE 26-6 Horizontal Bunsen Burner Test Cabinet

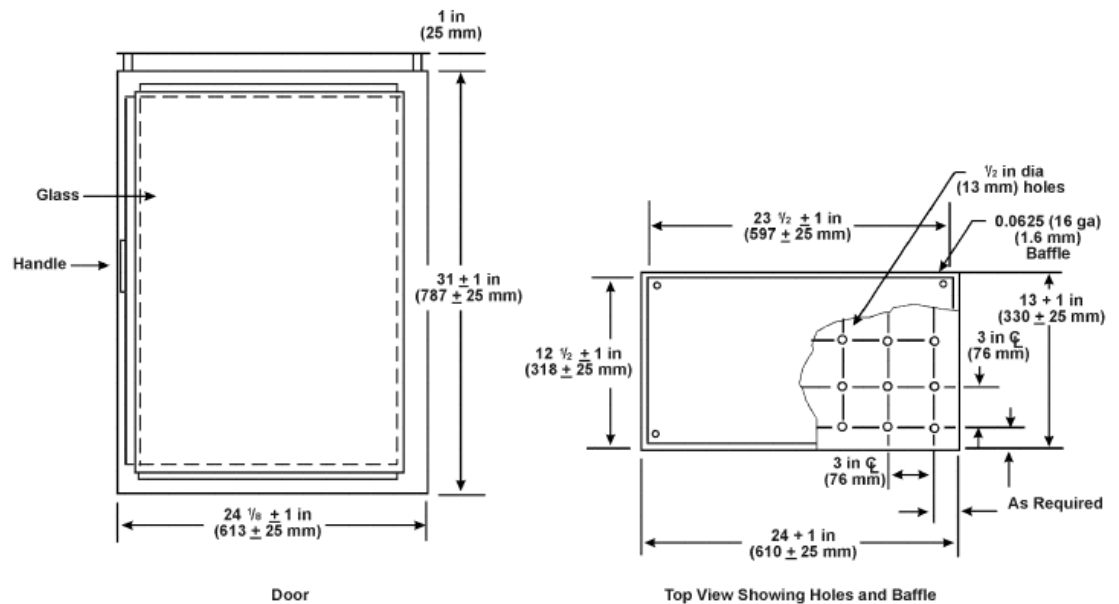
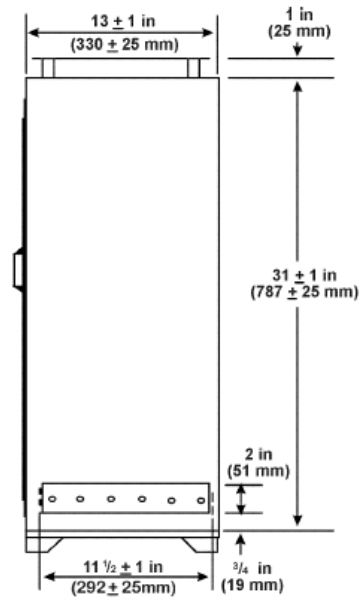
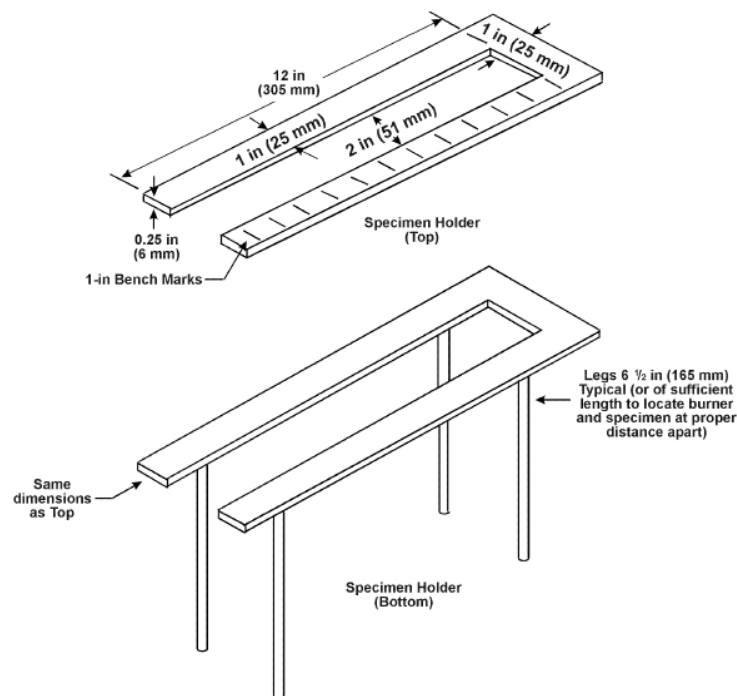


FIGURE 26-7 Front and Top View of Horizontal Bunsen Burner Test Cabinet



Right Side View

FIGURE 26-8**Side Views of Horizontal Bunsen Burner Test Cabinet****FIGURE 26-9****Horizontal Bunsen Burner Test Specimen Holder**

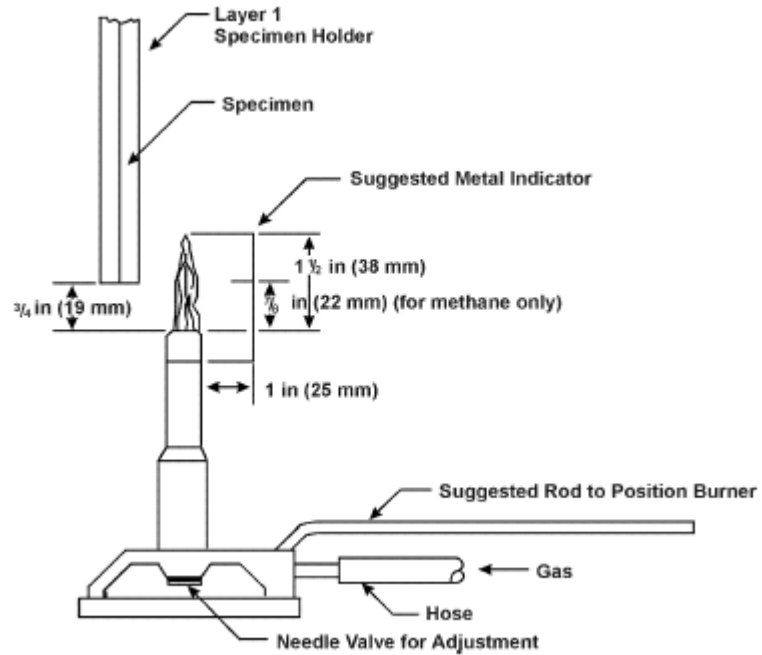


FIGURE 26-10 Burner Plumbing and Burner Flame Height Indicator

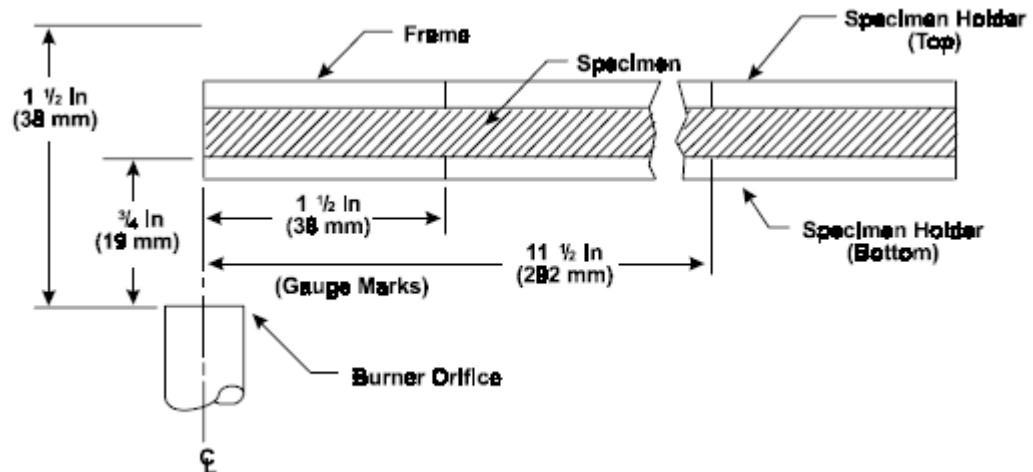


FIGURE 26-11 Typical Burner and Specimen location

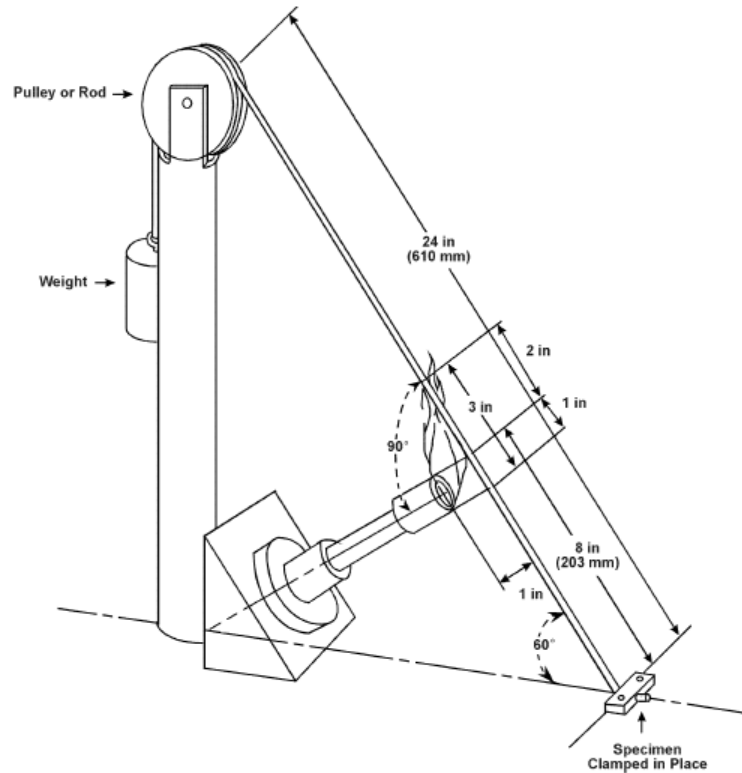


FIGURE 26-12 60-Degree Electrical Wire Bunsen Burner Test Setup

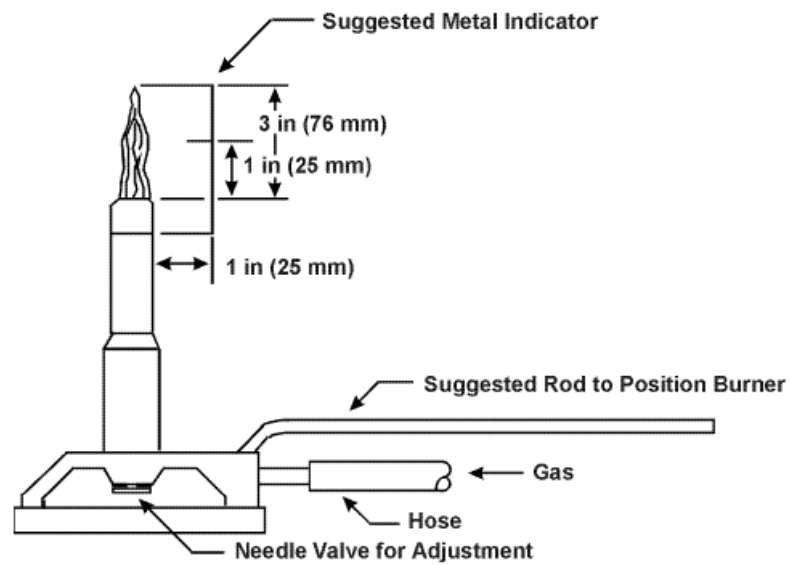
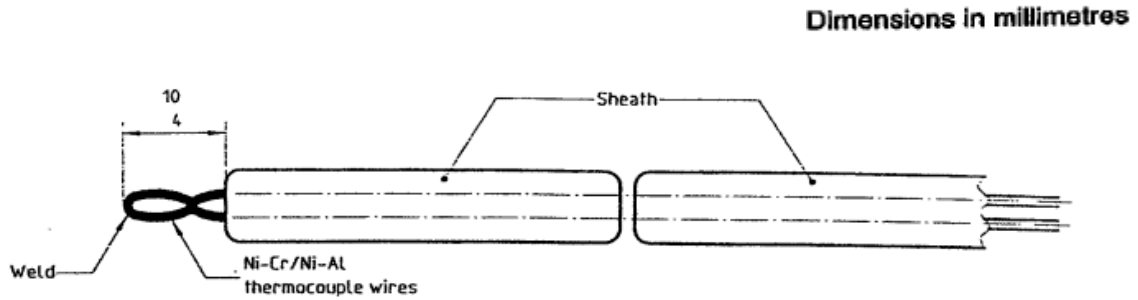


FIGURE 26-13 Burner Plumbing and Burner Flame Height Indicator



NOTES

- 1 The diameter of the thermocouple wire shall be between 0,6 mm and 1 mm.
- 2 If a metal sheath is used, the maximum diameter shall not exceed 3 mm. .118 max
- 3 The thermocouple shall be unshielded and non-aspirated.

FIGURE 26-14 Details of Thermocouple

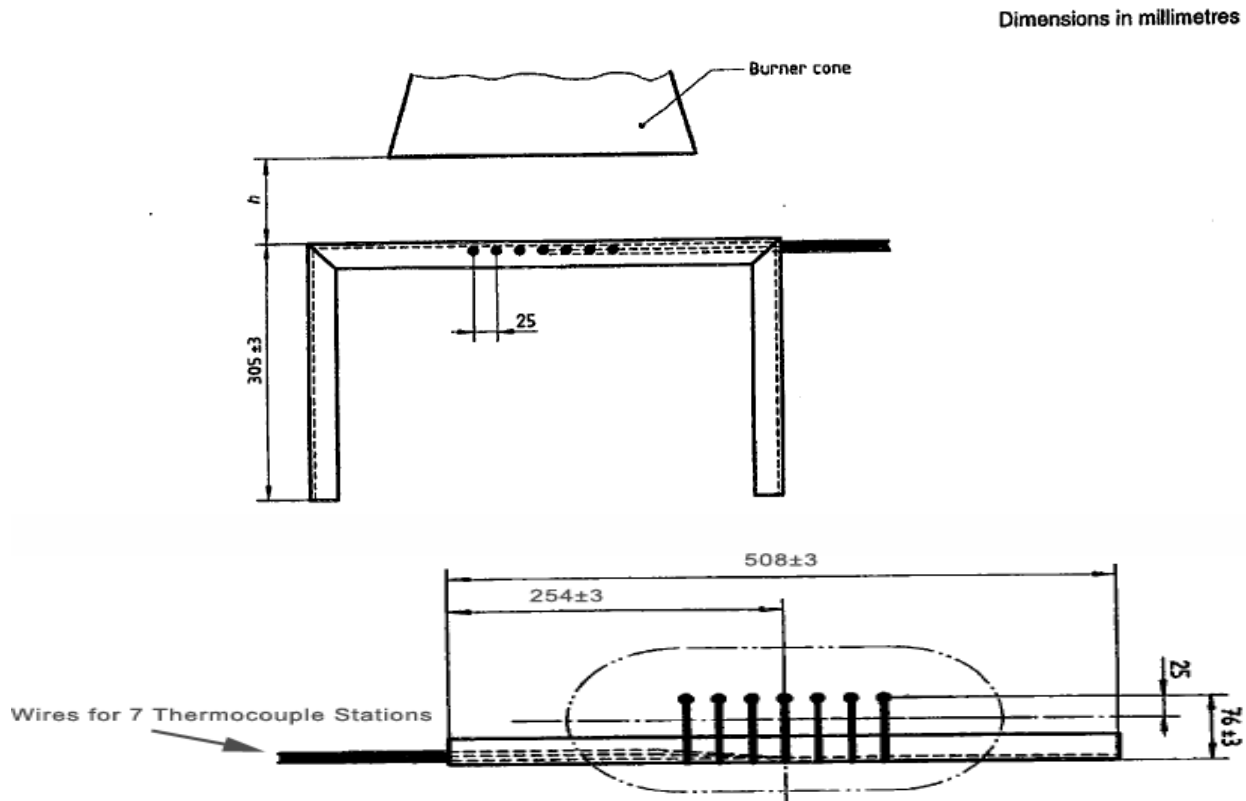


FIGURE 26-15 Liquid Fuel Burner – Thermocouple Positions
(burner shown in horizontal position)

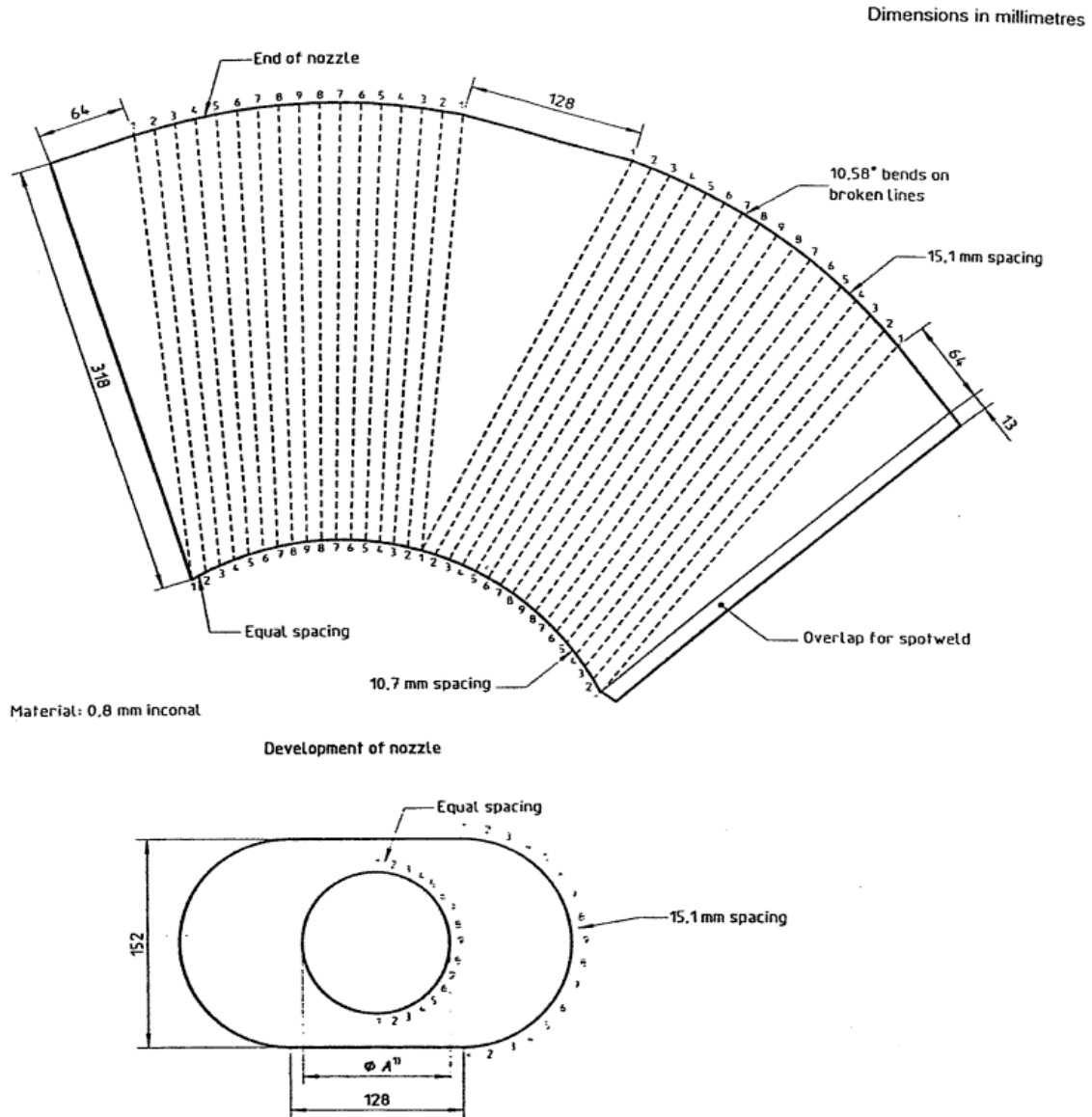


FIGURE 26-16 **Liquid Fuel Burner Nozzle**

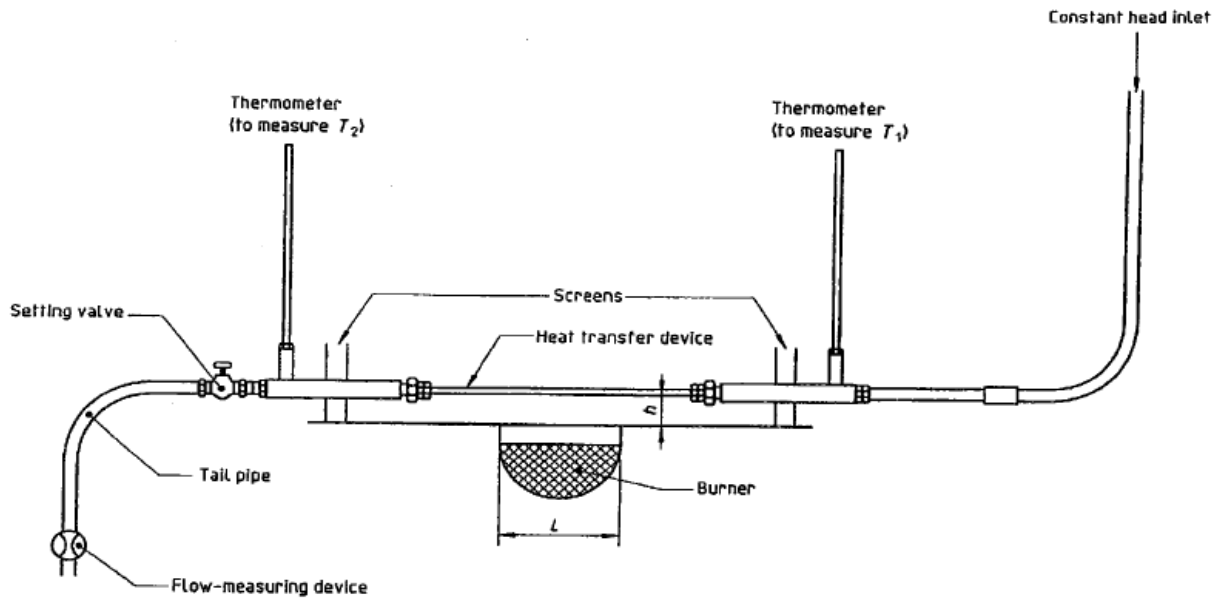


FIGURE 26-17 Set-Up of Standard Heat Flux Density Measuring Apparatus

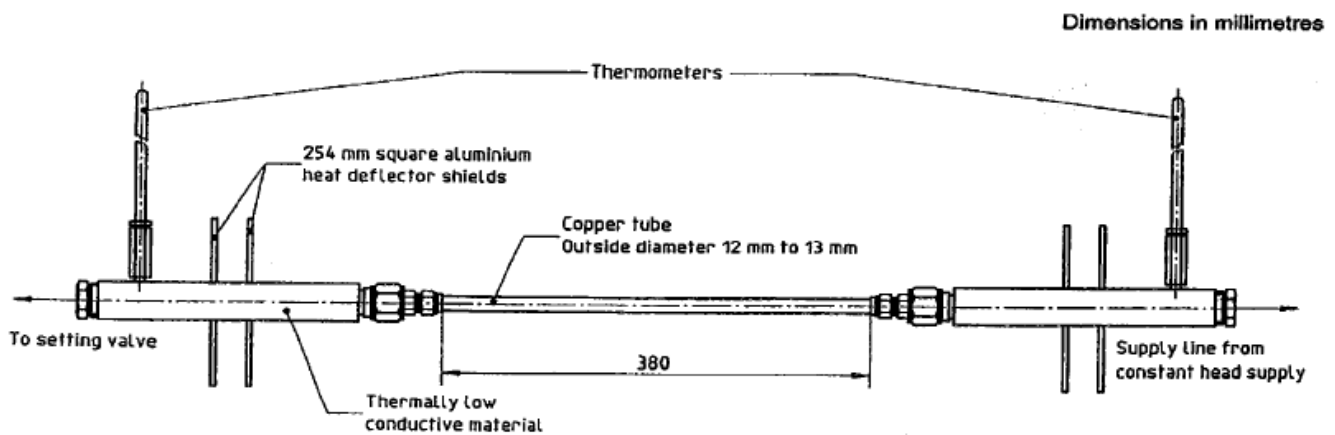


FIGURE 26-18 View of Mounting Heat Flux Density Measuring Tube

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

User's Guide Section 26

Fire, Flammability

Based on

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Prepared by: RTCA SC-135

G26.4, G26.5 There are numerous accepted fire test specifications and Advisory Circulars for conducting fire testing of components in designated fire zones. Some of these specifications are very specific for testing a particular component such as a hose conveying flammable fluid which may include a bend in the hose (in the fire area) as well as vibration on the product during application of the flame. Others are more generic and intended for all components in designated fire zones which may include gearbox accessories, firewalls, valves, etc. Because of the number of different specifications (accepted methods) and the variability of each, the test method presented in this section is intended as a guide, a test plan should be tailored to meet your approval agency.

G26.4.3 Advisory Circular AC No: 33.17-1 states: “The capability of a part or component to withstand, as well as or better than steel, **a 2000°F average flame temperature (± 150 F individual thermocouple tolerance)**”. This statement implies that the average temperature taken over the course of the calibration period shall have a minimum reading of 2000°F.

Figure 26-15 shows the burner in a horizontal configuration. The thermocouple rake is positioned 4 inches from the end of the burner extension cone and 1 inch above the centerline (due to flame buoyancy). If the burner is positioned in a vertical configuration the thermocouple rake shall be positioned on the centerline of the extension cone. This applies to the copper tube (flame intensity calibration device) placement as well.

G26.6 Flammability

G26.6.2 Vertical Burner

This supplement contains advisory material pertinent to referenced paragraphs. This test method is intended for use in determining the resistance of materials to flame when tested according to 12-second Vertical Bunsen Burner Tests specified in Federal Aviation Regulation (FAR) 25.853 and FAR 25.855. There is also a 60 second vertical test that is intended to show compliance for interior compartments occupied by crew or passengers. This method was not included because the intent of this 60 second test is for testing interior ceiling panels, interior wall panels, partitions, galley structure, large cabinet walls, structural flooring, and materials used in the construction of stowage compartments. As stated in paragraph 26.6.2.3, the methods to show compliance to category C are for enclosures housing electronics and non-metallic material, component parts, sub-assemblies installed in pressurized or non-pressurized zones and non-fire zones.

G26.6.2.1.1 Ignition time should start only after the flame has stabilized and is properly positioned under the test specimen.

G26.6.2.1.4 This definition of burn length is a clarification of that used in FAR 25, Appendix F, Part I, viz.: “Burn length is the distance from the original edge to the farthest evidence of damage to the test specimen due to flame impingement including areas of partial or complete consumption, charring, or embrittlement, but not including areas sooted, stained, warped, or discolored nor areas where material has shrunk or melted away from the heat source.” The main point is that “damage to the test specimen due to flame impingement” is clarified by “damage to the test specimen due to that area’s combustion” because it is a better description of the intent of the rule and is consistent with current test practices.

The burn length definition specified in FAR 25, Appendix F, applies to all materials listed in Part 25.853 and FAR 25.855. Since such a wide variety of materials require vertical Bunsen burner testing, areas that might obviously be included as burn length in some materials may not always be as well defined in others.

For the most part, these materials may be divided into four general categories; they are polymeric materials (such as panels, partitions, transparencies, etc., which may be hybrid or single plastic material), textiles, carpeting, and foams.

The following methods have been suggested for determining burn length:

- a. Polymeric Materials. In order to fix the boundary where the flame front was impinging on the specimen surface and damaging the specimen due to that area's combustion, i.e., below which combustion of the specimen occurred and above which it did not, it is necessary to observe the specimen continuously during the test. Flame impingement on the specimen may lead to outgassing due to thermal decomposition. As these gases burn, radiating heat may cause discoloration, sooting, staining, melting, etc., to areas above the flame front. This type of damage is not a result of thermal decomposition due to flaming and, therefore, would not be included in the burn length.
- b. Polyurethane Foams. Polyurethane foams are cellular in nature and, therefore, have low thermal conductivity. Since high surface temperatures are generated on exposure to the burner flame, an almost instantaneous conversion to flammable gases results. This, in turn, produces rapid surface flame spread with complete consumption of the foam immediately above the ignition source. By definition, complete consumption of an area is part of the burn length and should be included.

G26.6.2.2.1 Suitable test cabinets of the type described are manufactured by the U.S. Testing Co., 1415 Park Ave., Hoboken, New Jersey 07030; Atlas Electric Devices Co., 4114 N. Ravenswood Ave., Chicago, Illinois 60613; and The Govmark Organization, Inc., P.O. Box 807, Bellmore, New York 11710.

Draft free implies a condition of no air currents in a closed in space. One way of determining whether the cabinet is draft free is to place a smoldering and smoking material, such as a lighted cigarette, in the test cabinet, then closing the door and observing the behavior of the smoke for signs of drafts. A test cabinet other than one fabricated in accordance with

FIGURE 26-1 to Figure 26-2 may be found to be acceptable after review by the FAA.

The entire inside back wall of the chamber may be painted flat black to facilitate viewing of the test specimen, and a mirror may be located on the inside back surface to facilitate observation of the hidden surfaces.

G26.6.2.2.3 A suitable burner is available from Rascher & Betzold Inc., 5410 N. Damen Ave., Chicago, Illinois 60625, Catalog No. R3726A.

G26.6.2.2.3.3 The tip of the methane flame is blue, transparent, and difficult to see. It is more easily seen if there is no light on the flame, as in a darkened room. The inner cone of the flame is, however, more visible and easily seen and can be used to monitor flame height. When the flame height (blue transparent tip) is set to 1.5 inches, the height of the inner cone has been found to vary slightly from burner to burner, but is generally about 7/8 inch. Therefore, if the inner cone height is used to monitor flame height, the inner cone height needs to be established for that burner.

G26.6.2.3.3 By regulation, there must be at least 2 inches of the specimen exposed; however, the text specifies a specimen cut 3 inches in width. This allows enough material to ensure that the specimen is securely held in the holder. From experience, it has been found that materials such as films are difficult to secure in the holder and, therefore, may be cut even greater than 3 inches in width. This allows the operator adequate material to pull or adjust so that the specimen does not buckle or fall out of the holder.

G26.6.2.3.4 According to the FAR 25.853, the specimen thickness must be no thicker than the minimum thickness to be qualified for use in the airplane. If the test facility has found from experience or has questions concerning the flammability of a thicker specimen, then vertical testing may be conducted and test data recorded for further review.

G26.6.2.4 As stated in the FAR 25.853, only one specimen may be removed at a time from the conditioning chamber prior to being subjected to the flame. Some facilities, however, have conditioning chambers located in areas remote from the testing area. In this case, it is permissible to remove more than one specimen at a time only if each specimen is placed in a closed container (a plastic stowage bag is acceptable) and protected from contamination such as dirty lab tops, soot in the air, etc., until the specimen is subjected to the flame.

G26.6.2.6 Item 4 More information is available in DOT/FAA/CT-86/22, “An Investigation of the FAA Vertical Bunsen Burner Flammability Test Method.” Appendix F, FAR 25.853, Part I describes this test and specifies that the flame be placed “along the centerline of the lower edge.” The “centerline of the lower edge” is the line from the front face to the back face of the specimen. For thicker specimens, this is ambiguous since exactly “where” along the “centerline of the lower edge” is not specified.

Historically, test practices regarding burner flame placement have not been uniform or consistent within either the FAA or aircraft manufacturers. The most common placement used in the past was specified in the original issue of this handbook, viz.:

For specimens that are 3/4 inch (19 mm) thick or less, place the burner barrel centerline under the center of the bottom surface of the specimen.

For specimens thicker than 3/4 inch (19 mm), center the burner barrel under the bottom surface of the specimen 3/8 inch (10 mm) in from the surface exposed to the airplane interior, test each surface separately unless the surfaces are of the same materials and construction.

Another placement that has been less commonly used is that specified here, viz., directly under the middle of the lower edge of the face of the specimen that is exposed to the airplane interior. For specimens thinner than the burner barrel thickness (3/8 inch; 10 mm), test results are relatively insensitive to exactly where “along the centerline of the lower edge” the burner flame is placed. For samples of greater thickness, however, burn lengths are typically an inch or so longer if the burner barrel centerline is placed under or near the specimen face, and flame times are sometimes a little longer than if the flame is placed per the original handbook, Report DOT/FAA/CT-89/15, September 1990.

Materials used in contemporary (especially postheat release) designs produce burn lengths and flame times that are considerably less than the acceptance criteria for certification (6 inches and 15 seconds), regardless of where the flame is placed. Although where the burner flame is applied is not of important pass/fail significance in this test, placing it directly under the specimen face generally represents a worst-case situation.

The FAA should accept data for certification using the flame placement described in the original portion of this handbook, or using the flame placed under the exposed face of the test specimen. However, the FAA and aircraft manufacturers have agreed that in the future, the preferred placement of the burner flame is under the middle of the lower edge of the face of the specimen.

G26.6.2.6 Item 5 If the burner extinguishes during the ignition time for any reason, rerun the test. From experience, it has been found that this is a necessary requirement when running a 12-second test. The opposite end of the same specimen can be used for the retest if the burn length for the aborted test is less

than 3 inches (76 mm). If the burn length for the aborted test is greater than 3 inches (76 mm), a new specimen must be used.

G26.6.2.6 Item 8 The operator should refer to the facility's safety manual for further information on dealing with smoke and flammability by-products.

G26.6.3 Horizontal Burner

This supplement contains advisory material pertinent to referenced paragraphs.

G26.6.3.1.1 Ignition time should start only after the flame has stabilized and is properly positioned under the test specimen.

G26.6.3.2.1 Suitable test cabinets of the type described are manufactured by the U.S. Testing Co., 1415 Park Ave., Hoboken, New Jersey 07030; Atlas Electric Devices Co., 4114 N. Ravenswood Ave., Chicago, Illinois 60613; and The Govmark Organization, Inc., P.O. Box 807, Bellmore, New York 11710.

Draft free implies a condition of no air currents in a closed in space. One way of determining whether the cabinet is draft free is to place a smoldering and smoking material, such as a lighted cigarette, in the test cabinet, then closing the door and observing the behavior of the smoke for signs of drafts. A test cabinet other than one fabricated in accordance with Figure 26-6 to Figure 26-8 may be found to be acceptable after review by the FAA.

The entire inside back wall of the chamber may be painted flat black to facilitate viewing of the test specimen, and a mirror may be located on the inside back surface to facilitate observation of the hidden surfaces.

G26.6.3.2.3 A suitable burner is available from Rascher & Betzold, Inc., 5410 N. Damen Ave., Chicago, Illinois 60625, Catalog No. R3726A.

G26.6.3.2.6 The tip of the methane flame is blue, transparent, and difficult to see. It is more easily seen if there is no light on the flame, as in a darkened room. The inner cone of the flame is, however, more visible and easily seen.

G26.6.3.5.3 A 3-inch by 13-inch (76- by 330-mm) specimen can be used to secure the specimen at the end of the specimen holder.

G26.6.3.5.4 According to the FAR 25.853, the specimen thickness must be no thicker than the minimum thickness to be qualified for use in the aircraft. If the test facility has found from experience or has questions concerning the flammability of a thicker specimen, then vertical testing may be conducted and test data recorded for further review.

G26.6.3.6 As stated in the FAR 25.853, only one specimen may be removed at a time from the conditioning chamber prior to being subjected to the flame. Some facilities, however, have conditioning chambers located in areas remote from the testing area. In this case, it is permissible to remove more than one specimen at a time only if each specimen is placed in a closed container (a plastic stowage bag is acceptable) and protected from contamination such as dirty lab tops, soot in the air, etc., until the specimen is subjected to the flame.

G26.6.3.7.1 Item 4) It is important to note that the test should be watched carefully while it is being conducted. This applies to all samples.

G26.6.3.7.1 Item 6) Some laboratories turn the gas off upon completion of the test; however, the majority of test facilities, including the OEMs, withdraw the flame by moving the burner away from the specimen.

G26.6.3.7.1 Item 8) The operator should refer to the facility's safety manual for further information dealing with smoke and flammability by-products.

G26.6.4 60 Degree Burner

This supplement contains advisory material pertinent to referenced paragraphs.

G26.6.4.1.1 Ignition time should start only after the flame has stabilized and is properly positioned under the test specimen.

G26.6.4.2.1 Draft free implies a condition of no air currents in a closed in space. One way of determining whether the cabinet is draft free is to place a smoldering and smoking material, such as a lighted cigarette, in the test cabinet, then closing the door and observing the behavior of the smoke for signs of drafts. A test cabinet other than one described in section 26.6.4.2.1 may be found to be acceptable after review by the FAA.

The entire inside back wall of the chamber may be painted flat black to facilitate viewing of the test specimen, and a mirror may be located on the inside back surface to facilitate observation of the hidden surfaces.

G26.6.4.2.3 A suitable burner is available from Rascher & Betzold, Inc., 5410 N. Damen Ave., Chicago, Illinois 60625, Catalog No. R3726A.

G26.6.4.2.3.1 Gases such as natural gas and propane can be used as burner fuel. However, it should be required to show compliance with the 1750°F minimum flame temperature using a 24 AWG thermocouple.

G26.7.4.3.2 It is strongly recommended to have samples length of 30 inches. However, in the event that 30 inches of product is not available, actual length of test item may be used and additional non-flammable cable can be attached to item (metal clip or similar) to complete tension using pulley. In addition, the actual specimen length should be long enough to be able to demonstrate compliance to the < 3 inches burn length requirement.

G26.6.4.4 As stated in FAR 25.853, only one specimen may be removed at a time from the conditioning chamber prior to being subjected to the flame. Some facilities, however, have conditioning chambers located in areas remote from the testing area. In this case, it is permissible to remove more than one specimen at a time only if each specimen is placed in a closed container (a plastic stowage bag is acceptable) and protected from contamination such as dirty lab tops, soot in the air, etc., until the specimen is subjected to the flame.

G26.6.4.5.1 Item 4) Alternative Burner Placement

Place the burner into position so that the top end of the burner barrel is 1 inch from the mark on the specimen. Make sure the centerline of the burner barrel is perpendicular to the underside of the mark on the specimen, that the centerline of the burner barrel forms an angle of 30 degrees with the line that is in the vertical plane containing both ends of the specimen, is perpendicular to the specimen, and passes through the mark on the specimen. It has been found convenient to fabricate a fixture to position and hold the location of the burner quickly and repeatably (see Figure G26-19).

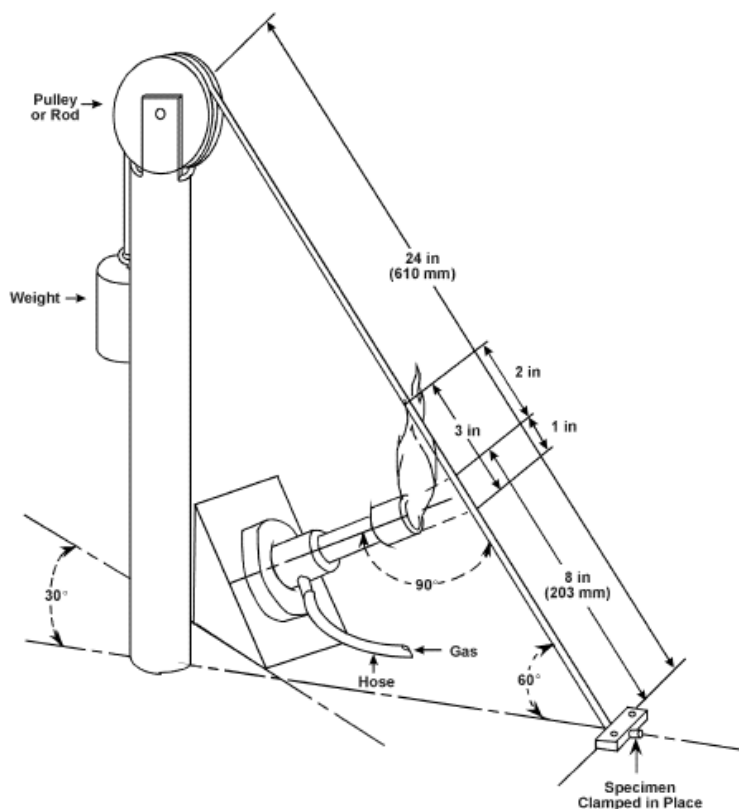


FIGURE G26-19 **Alternative Setup for 60-Degree Electrical Wire Bunsen Burner Test**

G26.6.4.5.2 Item 6) The operator should refer to the facility's safety manual for further information dealing with smoke and flammability by-products.

NOTE: The Alternative Burner Placement conforms to the 30-second, 60-degree Bunsen burner test described in FAR 25, Appendix F, Part I through Amendment 25-72. The FAA William J. Hughes Technical Center has determined that the Burner Placement in section 26.6.4.5.1, Item 4) produces equivalent test results.

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**Environmental Conditions and Test
Procedures for Airborne Equipment**

Appendix A

Environmental Test Identification

Important Notice

Information pertinent to this section is contained in Sections 1, 2 and 3. This appendix is applicable for identifying the environmental tests performed.

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December 8, 2010

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Prepared by: RTCA SC-135

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A.1 Introduction and Scope

A need exists to provide a permanent record of the particular environmental test categories that equipment has passed. This need includes post-incident or accident investigation, installation certification, repair, etc. This procedure provides for a paper record (hereafter referred to as the Environmental Qualification Form) to be included in the equipment data package submitted for Technical Standard Order (TSO) authorization and in the installation and maintenance instructions.

Since it is not envisioned that the Environmental Qualification Form will be related to a particular equipment by serial number or date of manufacture, association must be achieved through the equipment type, model or part number. Manufacturers should identify the method used to establish traceability to the environmental test categories to which the equipment was tested, including the applicable revision number of the test procedure (Section of RTCA/DO-160) used.

A.2 Environmental Qualification Form (see Figure A-1)

This form provides the necessary information regarding which environmental tests were conducted and, where applicable, the appropriate environmental category of the equipment being tested.

Additional information is included to identify the specific equipment type or model to which the environmental test results apply. A suggested format is depicted in Figure A-1. An example Environmental Qualification Form is shown in Figure A-2 and has been annotated to illustrate a completed form. Equipment manufacturers should expand on the data included on this form to provide added clarity.

In some cases, the manufacturer may wish to qualify the equipment to more than one category for a particular environmental test. In cases where multiple requirements for various categories exist, (e.g., Temperature/Altitude, or Vibration) more than one category may be indicated on the form, but only if the most severe requirement from each of the multiple requirements are met from all of the categories indicated. If all requirements for one category are clearly the most severe, only the most severe category need be identified.

Also, information such as vibration tests conducted with or without shock mounts, fluid tests conducted with Jet A fuel, type of de-icing fluid, and other parameters pertinent to the tests shall be included on the form.

Figure A-1 Environmental Qualification Form

NOMENCLATURE: _____

TYPE/MODEL/PART NO: _____ TSO NUMBER _____

MANUFACTURER'S SPECIFICATION AND/OR OTHER APPLICABLE SPECIFICATION: _____

MANUFACTURER: _____

ADDRESS: _____

REVISION & CHANGE NUMBER OF DO-160: _____ DATE TESTED: _____

CONDITIONS	SECTION	DESCRIPTION OF TESTS CONDUCTED
Temperature and Altitude	4.0	
Low Temperature	4.5.1	
High Temperature	4.5.2 & 4.5.3	
In-Flight Loss of Cooling	4.5.4	
Altitude	4.6.1	
Decompression	4.6.2	
Overpressure	4.6.3	
Temperature Variation	5.0	
Humidity	6.0	
Operational Shock and Crash Safety	7.0	
Vibration	8.0	
Explosive Atmosphere	9.0	
Waterproofness	10.0	
Fluids Susceptibility	11.0	
Sand and Dust	12.0	
Fungus	13.0	
Salt Fog Test	14.0	
Magnetic Effect	15.0	
Power Input	16.0	
Voltage Spike	17.0	
Audio Frequency Susceptibility	18.0	
Induced Signal Susceptibility	19.0	
Radio Frequency Susceptibility	20.0	

Figure A-1 Concluded

CONDITIONS	SECTION	DESCRIPTION OF TESTS CONDUCTED
Radio Frequency Emission	21.0	
Lightning Induced Transient Susceptibility	22.0	
Lightning Direct Effects	23.0	
Icing	24.0	
Electrostatic Discharge	25.0	
Fire, Flammability	26.0	
Other Tests		

REMARKS - - - - Special Conditions: Include power, special cooling, installation instructions, etc.

Figure A-2 Environmental Qualification Form

EXAMPLE

NOMENCLATURE: _____

TYPE/MODEL/PART NO: _____ TSO NUMBER _____

MANUFACTURER=S SPECIFICATION AND/OR OTHER APPLICABLE SPECIFICATION: _____

MANUFACTURER: _____

ADDRESS: _____

REVISION & CHANGE NUMBER OF DO-160: _____ DATE TESTED: _____

CONDITIONS	SECTION	DESCRIPTION OF TESTS CONDUCTED
Temperature and Altitude	4.0	Equipment tested to Categories A2, F2
Low Temperature	4.5.1	With auxiliary air cooling, tested to Category W
High Temperature	4.5.2 & 4.5.3	
In-Flight Loss of Cooling	4.5.4	
Altitude	4.6.1	
Decompression	4.6.2	
Overpressure	4.6.3	
Temperature Variation	5.0	Equipment tested to Category B.
Humidity	6.0	Equipment tested to Category A.
Operational Shock and Crash Safety	7.0	Equipment tested to Category B.
Vibration	8.0	Equipment tested to Category S, aircraft zone 4 for fixed wing turbojet engine aircraft, fixed wing unducted turbofan engine aircraft and fixed wing reciprocating/turbojet engine aircraft less than 5,700 kg using vibration test curves W and L.
Explosive Atmosphere	9.0	Equipment identified as Category X, no test performed.
Waterproofness	10.0	Equipment identified as Category X, no test performed.
Fluids Susceptibility	11.0	Equipment identified as Category F Equipment spray tested with phosphate ester-based hydraulic fluid and immersion tested with AEA Type 1 De-icing fluid.
Sand and Dust	12.0	Equipment identified as Category X, no test performed.
Fungus	13.0	Equipment tested to Category F.
Salt Fog Test	14.0	Equipment identified as Category X, no test performed.
Magnetic Effect	15.0	Equipment is Category A.

Figure A-2 Concluded

CONDITIONS	SECTION	DESCRIPTION OF TESTS CONDUCTED
Power Input	16.0	Equipment tested to Category A(CF), 400 Hz Alternate tests used for AC modulation and inrush AC harmonics and power factor not tested
Voltage Spike	17.0	Equipment tested to Category A.
Audio Frequency Susceptibility	18.0	Equipment tested to Category R(CF).
Induced Signal Susceptibility	19.0	Equipment tested to Category A.
Radio Frequency Susceptibility	20.0	Equipment tested for conducted susceptibility to Category R and for radiated susceptibility to Category R.
Radio Frequency Emission	21.0	Equipment tested to Category H .
Lightning Induced Transient Susceptibility	22.0	Equipment tested to pin test waveform set B, level 3, and cable bundle test waveform set D, Single/Multiple Stroke Level 4, Multiple Burst Level 3.
Lightning Direct Effects	23.0	Equipment identified as Category 2A2A, High Current Strike attachment, High Current Physical Damage
Icing	24.0	Equipment identified as Category X, no test performed.
Electrostatic Discharge	25.0	Equipment tested to Category A.
Fire, Flammability	26.0	Equipment tested to Category B.
Other Tests		Fire resistance tests were conducted in accordance with Federal Aviation Regulations Part 25, Appendix F.

REMARKS

- Tests were conducted at Environmental Laboratories, Inc.
- In the fluids susceptibility tests, material specimens were used
- In the power input test, equipment was tested to subparagraph 16.5.1.4 b, requirement for equipment with digital circuits.

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RTCA, Inc.

1828 L Street, NW Suite 805

Washington, DC 20036

RTCA/DO-160G

**Environmental Conditions and Test
Procedures for Airborne Equipment**

Appendix B

Membership

Date of Issue:
December 8, 2010

Supersedes: RTCA/DO-160F
Prepared by: RTCA SC-135

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Membership

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Environmental Conditions and Test Procedures For Airborne Equipment

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Honeywell International, Inc.

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General Electric Company

Jeff Dinsmore

Honeywell International, Inc.

William Donoghue

Pratt & Whitney Aircraft

Appendix B

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Terence Donohoe
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Brant Duke
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Robert Erlandson
Richard Errhalt
Marcelo Tadeu Ferreira
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Clayton Forbes
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DO-160G

**Environmental Conditions and Test
Procedures for Airborne Equipment**

**Appendix C
Change Coordinators**

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SC-135 / WG-14 Change Coordinators and Assignments

Section	Section Title	US Change Coordinator, Address, Phone / Fax / e-mail	EU Change Coordinator, Address, Phone / Fax / e-mail
1.0	Purpose and Applicability	Jim Lyall Embry-Riddle Aeronautical University 3700 North Willow Creek Road Prescott, AZ 86301 (P) 928-777-3833 (F) 928-777-6945 (E) lyallj@erau.edu	Marc Ponçon Eurocopter Marseille Provence Intl Airport (P) 33 4 42 85 7252 (F) 33 4 42 85 8765 (E) marc.poncon@eurocopter.com
2.0	Definitions of Terms	Jim Lyall	Marc Ponçon
3.0	Conditions of Test	Jim Lyall	Marc Ponçon
4.0	Temperature and Altitude	Jeff Dinsmore Honeywell, Inc. Aerospace Electronic Systems 8840 Evergreen Blvd., M/S MN 51-1305 Minneapolis, MN 55433-0640 (P) 763-957-4582 (F) 763-957-4731 (E) jeff.dinsmore@honeywell.com	Arnaud Ledreux Aeroconseil Immeuble Le Château 3, rue Dieudonné Costes BP 800 75 31703 Blagnac cedex FRANCE (P) 33 5 67 20 91 22 (F) 33 5 67 20 90 41 (E) arnaud.ledreux@aeroconseil.com
5.0	Temperature Variation	Jeff Dinsmore	Arnaud Ledreux
6.0	Humidity	Richard Errhalt Electronic Proving Ground Electromagnetics and Environmental Division - ETF Bldg. 82812, Arizona St. Fort Huachuca, Arizona 85613-7063 (P) 520-538-3928 (F) (E) richard.errhalt@us.army.mil	
7.0	Shock	Merrill Vaughan Boeing Commercial Airplane Company P.O. Box 3707, MS 03-KR Seattle, WA 98124 (P) 425-342-2277 (F) 425-717-0422 (E) merrill.d.vaughan@boeing.com	Marc Ponçon
8.0	Vibration	Merrill Vaughan	Marc Ponçon
9.0	Explosive Atmosphere	Gary Smith Honeywell International, Inc. 1300 W. Warner Rd Tempe, AZ 85284 (P) 480-592-3517 (F) 480-592-4906 (E) gary.smith7@honeywell.com	
10.0	Waterproofness	Gary Smith	

Appendix C

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11.0	Fluids Susceptibility	Gary Smith	
12.0	Sand and Dust	Richard Errhalt	
13.0	Fungus Resistance	Richard Errhalt	
14.0	Salt Spray	Richard Errhalt	
15.0	Magnetic Effect	Kenneth J. Webb Rockwell Collins 400 Collins Road, NE, M/S 106-183 Cedar Rapids, IA 52498 (P) 319-295-8667 (F) 319-295-0654 (E) kjwebb@rockwellcollins.com	Gilles Crousier Turbomeca Usine de bordes 64511 Bordes Cedex France (P) 33 5 59 12 58 26 (F) 33 5 59 12 51 48 (E) gilles.crousier@turbomeca.fr
16.0	Power Input	Paul Schwerman Honeywell, Inc. 21111 N. 19th Ave. Phoenix, AZ 85027 (P) 602-822-3691 (E) paul.schwerman@honeywell.com	C.Bertran Airbus France S.A.S 31060 Toulouse cedex France (P) (0)5 62 11 07 88 (F) (0)5 61 93 46 40 (E) christian.bertran@airbus.com
17.0	Voltage Spike Conducted	John Covell Goodrich Corporation Fuel and Utility Systems Vergennes, Vermont (P) 802-877-4594 (F) 802-877-4444 (E) john.covell@goodrich.com	Philippe Leroux Sagem (E) philippe.leroux@sagem.com
18.0	Audio Frequency Conducted Susceptibility	Ken Cechura Rockwell Collins 400 Collins Road, NE, M/S 106-183 Cedar Rapids, IA 52498 (P) 319-295-8494 (F) 319-295-0654 (E) krcechur@rockwellcollins.com	Henning Stöfen Airbus Deutschland GmbH Kreetslag 10, 21129 Hamburg, Germany (P): 49 40 743 69011 (F): 49 (0)40 743 870 69011 Email: henning.stoefen@airbus.com
19.0	Induced Signal Susceptibility	Jim Hatlestad The Boeing Company P.O. Box 3707, MC 03-CM Seattle, WA 98124-2207 (P) 425-266-1916 (F) 425-294-0830 (E) james.r.hatlestad@boeing.com	Tim Noad Qinetiq Cody Technology Park Ively Road, Farnborough Hants, GU14 0LX UK Tel: +44 1252 393382 Fax: +44 1252 397058 Email: tnoad@QinetiQ.com
20.0	RF Susceptibility (Radiated and Conducted)	Jim Hatlestad	Tim Noad

21.0	Emission of Radio Frequency Energy	Matthew Wills National Institute for Aviation research Wichita State University 1845 Fairmont St Wichita, KS 67260-0093 (P) 316-987-5776 (E) mwills@niar.wichita.edu	Henning Stöfen
22.0	Lightning Induced Transient Susceptibility	Erik J. Borgstrom Environ Laboratories LLC 9725 Girard Avenue South Bloomington, MN 55431 (P) (952) 888-7795 (F) Fax (952) 888-6345 (E) ejb@environlab.com	Jean.Patrick Moreau Dassault Aviation (E) jean-patrick.moreau@dassault-aviation.com
23.0	Lightning Direct Effects	Allan Meyer Rockwell Collins 400 Collins Road, NE Cedar Rapid, IA 52498 (P) 319-295-1528 (F) 319-295-3661 (E) ajmeyer@rockwellcollins.com	Jean.Patrick Moreau
24.0	Icing	Alan G. Thompson Environ Laboratories LLC 9725 Girard Avenue South Bloomington, MN 55431 (P) (952) 888-7795 (F) Fax (952) 888-6345 (E) agt@environlab.com	
25.0	Electro-Static Discharge	Erik J. Borgstrom	
26.0	Fire, Flammability	Alan G. Thompson	Sant-Anna Philippe Airbus France S.A.S 31060 Toulouse cedex France (P) 33 5 61 18 64 29 (F) 33 5 61 18 78 96 (E) philippe.sant-anna@airbus.com
Appendix A	Environmental Test Identification	Jim Lyall	Marc Ponçon
SC-135 / WG-14	Chairman	Bradley Green Honeywell International, Inc. Aerospace 23500 W. 105 th St. Olathe, KS 66061 (P) 913-712-2674 (F) 913-712-2674 (E) bradf.green@honeywell.com	Marc Ponçon

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SC-135	Secretary	Leo Makowski HV Technologies, Inc. 8515 Rixlew Lane Manassas, VA 20109 (P) 703- 365-2330 (F) 703- 365-2331 (E) makowski@hvtechnologies.com	Tim Noad
SC-135	Designated Federal Representative	Lee Nguyen Avionics Systems Branch FAA/AIR-130 800 Independence Ave, SW Washington, DC 20591-0004 (P) (202)385-4676 (F) (202)385-4651 (E) lee.nguyen@faa.gov	
RTCA	Program Director	Harold Moses 1828 L Street, NW, Suite 805 Washington, DC 20036 (P) 202-330-0654 (F) 202-833-9434 (E) hmoses@rtca.org	